Gatsby Occasional Paper

Raising Yields, Creating Partnerships:
Gatsby's On-Farm Work in Africa

'The Lamba who live near the copperbelt of Northern Rhodesia have such a legend. Long ago they say there were few Lamba and they had no proper food; they ate mostly wild fruits, leaves, and roots, and whatever else they could gather in the bush. Then a stranger came to live among the Lamba, 'a superior man' called Chipimbi, who brought with him seeds of maize, sorghum, groundnuts, and other crops unknown in Lambaland. Chipimbi did not come alone, his household came with him and his sister Kawanda Shimanjemanje and her household. The crops they brought to the Lamba were not known in Chipimbi's own country, which lay somewhere to the west of Lambaland. Kawanda Shimanjemanje was something of a traveller; she and her son had been to Lubaland on the Lualuba River where they had seen the great variety of crops grown by the Luba people, and by a stratagem obtained seeds of all of them. With this seed Chipimbi and his household planted gardens in Lambaland and gave food to the people. This, says the legend—or, rather, one version of it—was the beginning of Lamba agriculture and also of the institution of chieftaincy; for Chipimbi, the giver of food, became the first of their chiefs.'

Source: *The African Husbandmen* by W.H.Allen. Cited in *Africa's Way: A Journey from the Past*, by F.L.Cockroft. I.B.Taurus. London, 1989.

Cover photograph: *Increasing the yields of key food crops is vital for improving long-term food security in Africa. Besides raising farmers' incomes, it lowers the price of food for poor urban consumers. This has been the major focus of Gatsby's African Development Programme.*

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February 2003

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Foreword

The Trustees of the Gatsby Charitable Foundation have supported a range of projects in the developing world for over 20 years, both in the sphere of agricultural research and in direct action programmes designed to alleviate poverty. Nine per cent of grant payments made by the Trustees between 1991 and 2001 have been directed at supporting organisations in their work to improve the lives of people in Africa. In order to maximise the value of their support, the Trustees have, since the mid-1980s, concentrated resources within countries that have a reasonable degree of stability, and this has been done with the objective of supporting agricultural development, small-scale enterprise and the enhancement of education.

This report in the Gatsby Occasional Paper series reviews the Foundation's programme of support for agricultural research and technology dissemination in parts of sub-Saharan Africa. It describes some striking achievements, from the successful deployment of resistant crop varieties to combat the devastating effects of cassava mosaic disease in Uganda, to the development of an entirely new approach to the management of insect pests, pioneered in western Kenya and now being extended elsewhere. Gatsby shares the credit for these achievements with the many other donor agencies and partner institutions that have contributed to the work. The report also draws out the lessons learned from these experiences, which will be used to enrich the Foundation's future programme. A shorter version of the report is available on the Gatsby website (http://www.gatsby.org.uk/).

Complementing Gatsby's support for agricultural research is the Foundation's small-scale enterprise programme, which is delivered through four largely independent Trusts in Cameroon, Kenya, Tanzania and Uganda. This programme, which contributes to the development of charitable institutions anchored in the local community, is described in another Gatsby Occasional Paper, entitled *Building from the Base: The Work of the African Gatsby Trusts.* Published in 1998, this paper is also available on the Gatsby website.

The Trustees of the Gatsby Foundation appreciate the hard work of all the organisations and individuals, both in developing countries and based at research centres in the UK, who have struggled to advance their knowledge and apply it to improving crop yields in Africa. Though much remains to be achieved, these efforts have undoubtedly helped to improve the lives of many Africans—both those directly reliant on small-scale agriculture for their livelihoods and the many urban consumers who urgently need cheaper food and other basic commodities. The Trustees would also like to express their gratitude to Green Ink Publishing Services Ltd for their appraisal of Gatsby-supported work in this area, and for delivering this useful and thought-provoking report.

The Trustees of the Gatsby Foundation believe that the experiences described in this report will be relevant to all those interested in agricultural development in Africa. They hope that this paper will provide practical lessons valuable to those working with small-scale farmers in order to increase the productivity of their farms and improve the quality of their lives. They would also appreciate the comments of others at work in this challenging field.

Michael Pattison CBE
Director
The Gatsby Charitable Foundation
London, February 2003

1. New paths to prosperity in Africa: intervening to support agricultural innovation

Food insecurity is a major issue for sub-Saharan Africa, as the world was reminded at the second World Food Summit held in Rome in the summer of 2002.

According to the United Nations Food and Agriculture Organization (FAO), the number of people suffering from food insecurity in sub-Saharan Africa is rising. One important factor in this regard is the low productivity of key African crops. The 'yield gap' between the yield these crops should be able to achieve under ideal conditions and what they actually produce has, for some time, concerned many involved with African agriculture and its improvement. Cereal yields in sub-Saharan Africa today are still well below those in Asia. The yields of cassava, a vital food crop for poor households, are about half those achieved in Asia and South America. Increases in production are mainly achieved through expansion of the area cultivated, rather than through productivity gains.

Yet some examples of progress provide encouraging exceptions to these otherwise disheartening trends. In Cameroon, cassava yields tripled over the 30 years between 1961/3 and 1991/3, and neighbouring Nigeria is now the world's largest producer of cassava. Maize yields in Kenya and South Africa are now broadly similar to those in South Asia. These success stories—the result of focused, relevant research and committed, energetic development—show that significant yield improvements are possible for African agriculture.

In 1986, Gatsby launched its programme to promote agricultural development in Africa by providing support to the Cameroon National Root Crop Improvement Project. The centrepiece of the project was a researcher-led effort to disseminate to farmers large quantities of high-yielding, disease-resistant cassava varieties developed by the International Institute of Tropical Agriculture (IITA). This, Gatsby's first Africa project, formed part of Cameroon's success story. Learning from this and other experiences that followed, the Foundation's agenda and its portfolio of projects have evolved greatly over time (see box).

This report reviews the agricultural research and development projects that Gatsby has supported in Africa over the period 1986–2001, and synthesises the lessons learned in the course of this experience. It is based on a review of project documents and a series of interviews with the researchers, development workers and farmers involved in the projects. The work was conducted in early 2002 by staff of Green Ink Publishing Services Ltd, in close consultation with Gatsby staff and advisors.

Priorities for a more effective development agenda

Gatsby's investment policy [1] is guided by the belief that the greatest positive impact on the productivity of agriculture in Africa can be achieved by (in order of priority):

- Increasing the effectiveness of institutions designed to support farmers (by providing improved seed and other inputs, credit and other financial services);
- Breeding improved crop varieties by conventional means;
- Developing biological control and other sustainable crop management practices to reduce the impact of pests and diseases and improve soil fertility;
- Using the tools of biotechnology to enhance conventional crop improvement and to support the development of pest and disease management strategies.

[1] Based on: F.L.Cockcroft (1999), Priorities for the Gatsby Foundation in Agricultural Research and its Dissemination in Africa. Unpublished report.

Chapter 2 examines the achievements of a range of individuals and organisations in improving cassava yields in Cameroon. Importantly, it also examines the taming of an epidemic of cassava mosaic disease (CMD) in Uganda that destroyed some 2000 hectares of the crop in Luwero District alone in 1988, threatening thousands with starvation. With support from the international research community and donors such as Gatsby, national researchers and their partners were able to test, multiply and disseminate a range of new, high-yielding cassava varieties that were resistant to CMD. A decade later, in 1998, national cassava production had returned to pre-epidemic levels, widespread famine had been averted and farmers' incomes from cassava had increased.

Chapter 3 focuses on how new varieties of rice have been made available to farmers in Ghana and Nigeria, and new varieties of beans made available to farmers in Uganda, in order to help combat the low yields resulting from viruses and pests. The chapter emphasises the importance of researchers working with farmers to understand their needs, if a good take-up of new higher yielding varieties is to be ensured. The importance of developing systems which allow new seed varieties to be multiplied as quickly as possible is also stressed. In Uganda, researchers experimented with a new seed loan system whereby farmers were given 2 kilogrammes of bean seed initially, but had to return the same amount after their first harvest and were encouraged to give away seed to their neighbours. The pilot phase began in Apac District in 1997 with 20 farmers. After only one year 1500 farmers had access to the new varieties and today more than 6000 do.

The potential for modern biotechnology to help African farmers improve their crop yields is also clear from this review. Gatsby, through its support for plant science research in the UK and through its strong links with the research community, has been well placed to help facilitate international collaboration to this end. As detailed in Chapter 4, research at the John Innes Centre (JIC) in Norwich played an important role in overcoming problems that arose with new varieties of banana and plantain (*Musa*), developed by IITA in response to a range of problems that had contributed to falling yields over a 20-year period for small-scale producers across Africa. Whilst the new varieties yielded an excellent crop of fruit, there were reports that the plants were showing what appeared to be virus symptoms. This was despite the fact that the tissue-cultured materials distributed by IITA were routinely tested to ensure that they were free of virus diseases before shipping. Following some years of research, scientists at JIC eventually solved the mystery by uncovering a previously unknown kind of virus behaviour, which kept the virus hidden until the host plant came under some kind of stress.

Forestry issues are important because fuelwood is still the main source of domestic energy for cooking throughout most of sub-Saharan Africa, and is also a power source for many of Africa's small-scale processing industries. These issues have also been addressed. Chapter 5 describes how rapid multiplication based on tissue culture, together with an improved rooting technique, is being used to produce a large number of genetically uniform, disease-free plantlets in a short space of time. Varieties of eucalyptus that have high growth potential and are resistant to disease and stress have proved highly successful in Kenya. Here an experimental partnership has been entered into between Kenya's Forestry Department, the private timber company Mondi Forests of South Africa, the International Service for the Acquisition of Agri-biotech Applications (ISAAA) and Gatsby. Free access to clones developed by Mondi was secured when Gatsby met the start-up costs of establishing a dissemination programme for improved tree technology in Kenya.

Not surprisingly, work supported by Gatsby has experienced both successes and failures—sometimes within a single project. When IITA was established in 1967, to bring the techniques of the Green Revolution to bear on Africa's food crisis, two traditional staple crops of West Africa—cowpea and yam—were among the priority candidates for improvement. Traditionally, plant breeders had neglected both crops. Twenty-five years of research and investment, using conventional crop breeding techniques, led to considerable progress. But as each pest, disease or physiological constraint was alleviated, another came to the fore, blocking the path towards higher productivity. In the early 1990s, scientists at JIC and IITA began applying their knowledge and expertise in molecular biology to these problems.

Current approaches to rural development stress the need to develop institutional support in parallel with technological innovation. Market opportunities, such as the chance to sell these bananas into the urban market of Kampala, provide farmers with a strong incentive to adopt new crop varieties.

New supporting technologies, such as gene maps of yams and cowpea and molecular diagnostics for yam viruses, were developed. Chapter 6 reviews the achievements of this work, and the scientific frustrations and unfortunate blind alleys that let to the project being deprioritised, when faced with the major new investments needed to give it a reasonable chance of success. The situation has also been complicated by the controversy over genetically modified crops in Europe.

Effective management systems also have a key role to play in improving productivity on African farms. Chapter 7 discusses this issue in relation to maize production. Unreliable rainfall, soil erosion, and pre- and post-harvest pest infestation are major challenges for small-scale farmers growing maize in Kenya, Tanzania and Uganda. Researchers at the UK's Institute of Arable Crops Research (IACR)–Rothamsted have collaborated with researchers at the Mbita Point field station of the International Centre of Insect Physiology and Ecology (ICIPE), the Kenya Agricultural Research Institute (KARI) and the Kenyan Ministry of Agriculture, in order to develop a 'push–pull' approach to insect pest management. As a result of this work Kenyan maize farmers, for example, now intentionally manage wild grasses like Napier as a 'trap crop'. Stemborers can reduce maize yields by as much as 80%, but Napier grass is a natural host, which, it turns out, attracts the stemborer away from the maize. The forage legume *Desmodium*, introduced to the system to improve its appeal to livestock producers, had the additional unexpected benefit of ridding maize fields of the devastating parasitic weed *Striga*. Other intercrops have been developed that act as a repellent to the stemborer – the 'push' part of the strategy.

Chapter 8 concludes with an overall assessment of the work that Gatsby has funded and been involved with in this area, over the past 17 years or so. A number of interesting and important issues are raised for further consideration. For instance, most of the technology dissemination projects involve 'researcher-managed extension', in which the scientists who helped to develop the new varieties or crop management strategies become 'product champions', taking responsibility for enabling farmers to adopt their product. Within this general theme, the report notes that there has been an evolution towards the increasing use of participatory research and training techniques, which help farmers to gain ownership of technologies and adapt them to their own needs. However, the greater costs involved with such participatory research are also noted, and the question of what is the most effective balance between this and other kinds of research remains one for further discussion.

The evolution of the projects also took place within a changing public policy environment, involving economic structural adjustment and liberalisation. A major effect of this background change has been the disintegration—or at least the severe weakening—of publicly funded extension services. The researchers leading the extension effort have responded by working with an increasingly diverse consortium of public- and private-sector entities. Indeed, these Gatsby-funded projects were among the first to develop what has now become a more modern model of integrated research and development (see box). Gatsby and its partners have recently launched an innovative programme, the Maendeleo Agricultural Technology Fund, which seeks to explore further, and to capitalise on, the opportunities for such partnerships.

A further result of this changing economic context is that the private sector is playing a growing role in technology dissemination. Correspondingly, the projects themselves place increasing emphasis on assuring the economic viability of new technologies and new models of dissemination. This already extends to seed production and is likely to extend in the future to marketing and credit. In this regard, the experiences of the Gatsby African Trusts, which support micro-enterprise and micro-finance, are likely to be relevant.

In the face of the challenges that confront Africa and its farmers, it is hoped that this report, in reviewing and assessing the experience of Gatsby-supported work, will be of interest and use to others concerned with the effectiveness of agricultural research and development (R&D) in Africa.

New partnerships for research and development

Inadequately resourced extension services were often the weak link in conventional technology transfer, leaving a gap between farmers and researchers that was hard to bridge. Farmers were unaware or mistrustful of the benefits of new technologies; meanwhile researchers, unaware of farmers' real priorities, sometimes developed or supplied technologies that were ill-suited to farmers' needs.

New arrangements that encourage researchers to take responsibility for technology dissemination have led to multiple benefits, including better two-way communication between farmers and researchers, the generation of more relevant technologies and wider, more rapid adoption. As farmers, extension workers and researchers have become partners, mutual respect and understanding have been enhanced, to the benefit of the development process.

Farmers in Ifote-Egbeda village, Ogun State, Nigeria, tell scientists what they think of the new rice varieties they have been jointly evaluating.

2. From crisis to confidence:
how improved cassava turned the tide

A spectacular turnaround

Since independence in 1962, Uganda has suffered long periods of political instability, poor governance and civil war. By 1986, when President Museveni took office, the agriculture-based economy of this green and fertile country, once described as the Pearl of Africa, was in ruins. In the Luwero Triangle north of Lake Victoria, formerly amongst the most productive agricultural regions in the country, an estimated 150 000 people had lost their lives, much of the cultivated land had been overrun by weeds, and most of the livestock had been slaughtered. One of the reasons why Ugandans had for the most part been able to feed themselves despite this devastation was their growing dependence on cassava as a major staple food. Yet, just when the prospect of stable governance was giving people renewed hope for the future, this vital safety net was rudely torn away. By 1988 an epidemic of cassava mosaic disease (CMD) of unprecedented severity had destroyed some 2000 hectares of the crop—enough to feed half the Luwero District for a year—and thousands were facing starvation.

Over the next 10 years, a dedicated band of researchers from Uganda's National Agricultural Research Organization (NARO) systematically tackled the problem. With support from Gatsby, other donors [1] and the international research community, NARO's team were able to test, multiply and disseminate a range of new, high-yielding cassava varieties that were resistant to CMD. By 1998, eight such varieties had been released and national cassava production had returned to pre-epidemic levels; indeed, in the following year production rose to a new high. Famine, food shortages and poverty had been greatly alleviated, particularly in the north and east of the country; exports of fresh roots and dried cassava chips to neighbouring countries had grown; and farmers had been equipped with the knowledge to manage this and other cassava production problems in the future. [2]

Whole villages went hungry when Uganda's CMD epidemic struck with devastating force.

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[1] Additional financial support was provided by the Rockefeller Foundation, the International Development Research Centre (IDRC) of Canada, the Department for International Development (DFID) of the United Kingdom, the Office of Foreign Disaster Assistance (OFDA) of the United States and the Government of Uganda.

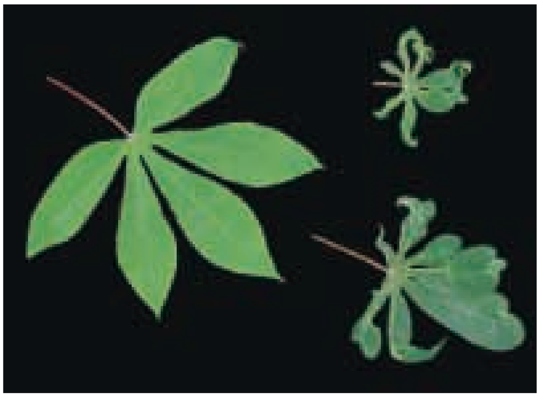
[2] A full account of this project is available in: Mastering Mosaic. The Fight for Cassava Production in Uganda. Gatsby Occasional Paper, London,1997.

By any standards, the taming of Uganda's CMD epidemic in such a short time was a remarkable achievement. Full credit must go to NARO's courageous team, who faced scepticism, hostility and even personal danger in their task. But their success also derived from two other factors: the experience gained by Gatsby and other partners in an earlier cassava dissemination project in Cameroon; and a decades-long tradition of free exchange, among public-sector research institutes, of the products of plant breeding and other agricultural research. This earlier work provided a platform for rapid and effective action in Uganda. The dissemination system developed by NARO allowed the adoption of improved varieties on a scale unprecedented in East Africa and in turn has provided a model for similar development efforts elsewhere.

Humble beginnings

Cassava was widely held in low regard by agricultural departments in pre-independence Africa, as a crop of low nutritional value that impoverished soils. In fact this crop was already filling a niche as the staple carbohydrate source of last resort in areas where population pressure and incautious intensification were starting to degrade the natural resource base. As demographic pressures increased in the 1960s and 1970s, exacerbated by drought and conflict, cassava gained an ever wider significance. Because traditional cassava varieties grow their starchy roots steadily over a period of up to two years—and then can be left in the ground without serious deterioration—they can be used as an on-farm food reserve, planted when the farmer can find the time and harvested when the family needs food or cash. Although higher yields are achieved on fertile soils, cassava will produce something on even the poorest soils, where more demanding crops such as maize would fail. And when drought comes, cassava simply drops its leaves and waits for better times, the roots remaining in the ground to save the farm family from famine. By the 1980s the crop was one of Africa's most important staple food crops, providing more than half the calorific needs of some 200 million people.

Meanwhile, plant breeders had been pursuing two strategies to improve cassava's yield potential: one was to breed a plant that filled its roots more quickly, achieving the greater part of its yield within a single growing season; the other was to provide resistance to CMD, a disease so ubiquitous that farmers believed its characteristic yellow mottling and deformation of the leaves to be simply a normal feature of the cassava plant itself.



Yellow mottling of the leaves is a characteristic CMD symptom.

Researchers working in the 1930s in East Africa had shown that CMD is caused by a virus transmitted by the whitefly *Bemisia tabaci* and that the disease can significantly reduce root yields. They had also demonstrated that, so long as the disease pressure was not too high, farmers could keep ahead of the disease by selecting symptom-free cuttings to start their crop and by 'roguing out' any plants that developed symptoms during the growing season. Such 'sanitation' measures are still part of recommended disease management practices for CMD today.

The first disease-resistant varieties were developed in East Africa by crossing edible cassava, *Manihot esculenta*, with a tree-like relative, *Manihot glaziovii*, originally brought from South America as a source of rubber. Some varieties derived from these crosses were transferred to Nigeria in the 1950s to support a crop breeding effort there, and this material in turn provided a basis for further progress when IITA, established in Nigeria in 1967, began its own intensive cassava breeding programme in the early 1970s. The cassava team at IITA, led by Dr Sang Ki Hahn, brought in more germplasm from the crop's centre of origin in South America as well as from Asia, where high-yielding cassava was already becoming a profitable export crop. By crossing the African and exotic cultivars, the team soon had varieties that were resistant to both CMD and cassava bacterial blight (CBB), an even more destructive disease that had recently appeared in Africa. These new varieties accumulated most of their root yield in only 10 to 12 months and outyielded local varieties by two to five times, depending on the situation.

Farmers greeted the new varieties enthusiastically but, officially at least, IITA initially took no direct part in extension efforts. Promising varieties and breeding lines were handed over to Nigeria's National Root Crops Research Institute, where researchers further tested the materials and made their own crosses. Private-sector companies and non-government organisations (NGOs) were among the first to take up the challenge of multiplying and distributing the new varieties released as a result of this further work. Then, in 1982, Nigeria's National Seed Scheme joined the effort, distributing to World Bank-funded agricultural development projects (ADPs) enough cuttings to plant some 20 000 hectares with improved varieties. In southern Nigeria, where there is a strong tradition of small-scale trading, many cuttings also spread from farmer to farmer. By 1985 it was estimated that one-fifth of the area of cassava in Oyo State, where IITA is based, was planted to the improved cultivars and by 1987 this figure had risen to about one-third. Over subsequent years, Nigeria became one of the world's largest producers of cassava.

Two factors contributed to the immediate success of these new varieties: firstly, they had been selected to suit local tastes and, secondly, the economic environment for their production and processing was favourable. Much of the cassava produced in southern Nigeria is bitter in taste and unsuitable for immediate consumption. Instead it is soaked, partially fermented and grated, to reduce the content of potentially toxic cyanogenic glucosides; it is then pressed and fried to produce a dry, granular product known as *gari*. Farmers adopting the new varieties were able to reduce the cost of producing *gari* by 20% and to increase their net income by 85%.

Underlying the appropriateness of the technology, however, was a third factor. 'Long before it became fashionable to do so, Sang Ki Hahn used to invite farmers into his breeding nurseries to discuss the new materials with them,' explains Dr Rodomiro Ortiz, head of IITA's Crop Improvement Division and a former plantain breeder in Nigeria. 'This was participatory varietal selection before the process had a name.' Hahn, who was awarded a Yoruba chieftaincy for his efforts on behalf of cassava farmers, took the issue of taste and processing characteristics seriously. The varieties he selected not only did well under farm conditions, quickly forming a closed canopy that reduced the need for weeding, but also made excellent *gari*.

The story of high-yielding cassava in Nigeria illustrates some of the conditions for success identified in a Gatsby-funded policy study carried out by Prof Paul Mosley of the University of Sheffield, UK.[3] The new varieties contribute to poverty alleviation because they offer farmers an increase in production and income without requiring them to invest more in inputs such as fertilisers and pesticides. In contrast to more demanding crops, such as rice or hybrid maize, they promise higher returns without increasing risk—indeed, because of enhanced disease resistance they may actually decrease risk. And, where labour markets are favourable, they generate wage-earning employment in both production and processing.

Seizing an opportunity

By the time Gatsby stepped onto the African agricultural development scene in 1985, it was clear that improved cassava had tremendous potential to enhance food security and reduce poverty in the region. The technology appeared to be ready for adoption by farmers; it had an energetic champion, in the form of Hahn; and IITA's network of national partner organisations, linked by training and collaborative research interests, offered a pathway to wider dissemination. The main constraints appeared to lie in the slow pace of multiplication of this vegetatively propagated crop and in the weakness of national seed multiplication and extension services which, under conventional

[3] This project, which is still ongoing, looks more broadly at the constraints and opportunities affecting agricultural development in Africa. Its findings to date are published in a series of occasional papers available from the Department of Economics, Sheffield University.

development models, should have taken responsibility for dissemination.

It looked as if both these constraints could be overcome. The spread of improved cassava in Nigeria, through a variety of opportunistic, researcher-led alliances with private and public organisations, offered a plausible new institutional model for dissemination. On the technical side, IITA was developing a system of accelerated multiplication of cassava based on the use of 'ministem' cuttings. A conventional cassava cutting is a section of woody stem perhaps a foot long, consisting of a dozen or more internodes. It is hardy and will establish a new plant in the face of drought, grasshopper attack or other stresses—but each parent plant will provide only about half a dozen such cuttings. A ministem cutting consisted of only one or two internodes. Ten times more cuttings could be taken from a single plant, vastly increasing the potential multiplication rate.

The ministems, however, had to be sprouted and nurtured carefully through their vulnerable early stages, on sterile soil and with adequate water. These requirements in turn led, on the organisational side, to the development of a 'cascade' system of nurseries. Researchers maintained the parent stocks of new varieties, ensuring that they remained disease free and capable of the fastest possible initial multiplication. Farmers were invited to assess the materials in the nursery for plant type, yield and processing qualities. The preferred varieties were then passed on for conventional multiplication to a limited number of sites—research sub-stations, schools, prisons and development projects—where the researchers could still keep an eye on the process and offer some training in improved crop husbandry. And from these sites the cuttings were distributed to farmers and community organisations, beginning the phase of informal dissemination.

These technical and institutional innovations provided the opportunity to speed up the dissemination of improved cassava in other African countries—an opportunity Gatsby decided to sieze. The first country chosen for its support was Cameroon, where the National Root Crop Improvement Programme was already strong, having benefited from collaboration with IITA dating back to 1978 and enjoying continuing support from Canada and Belgium. The national researchers undertook multi-location trials of the IITA varieties and found that some were well suited to local conditions and tastes. With the advent of Gatsby funding specifically targeted to support multiplication and dissemination, the prospects for rapid, widespread adoption looked good.

Local enterprise provides a solution

'The Gatsby philosophy from the start was to make already existing new technologies available to farmers and so to create an impact rapidly,' recalls Dr James Whyte, an IITA scientist who is a veteran of the cassava multiplication projects in both Cameroon and Uganda. Previous official policy in Cameroon, as in many other African countries, had required researchers to stay on the research station, handing their 'finished products' to government extension organisations for transfer to farmers. Now additional resources would be given to the researchers to champion their products at village level—and to hear first hand from farmers about their advantages and disadvantages. Chief Hahn's informal, populist approach to choosing varieties had produced materials that fitted the needs of farmers in southern Cameroon—an area ecologically similar to eastern Nigeria—and his practice of inviting farmers into the nurseries to help select the materials for multiplication was deliberately pursued in the new project. As in Nigeria, experience in Cameroon quickly showed that farmers tended to adopt the new varieties to grow as a cash crop, a trend that fitted in well with Gatsby's policy of promoting local enterprise.

Not everything went according to plan, however. Initially progress was delayed by a divergence of opinion between those project participants who wanted to focus on institution building and those who preferred to pour all possible resources into achieving grass roots impact. Matters were resolved in favour of the latter strategy when Gatsby proposed a novel experiment which would leave the nucleus nurseries in the hands of the national Institut de Recherches Agronomiques (IRA) while the private sector, especially groups of women farmers, would take responsibility for downstream multiplication. The multiplication effort was financed through the nascent Cameroun Gatsby Trust (CGT).

Following the model for the Gatsby Trusts already established in East Africa, a national board was set up with representatives from the public and private sectors. The board was co-chaired by Dr Jacob Ayuk Takem of IRA and Dr Paul Fokam, who had recently established a private savings institution, the Caisse Communale d'Epargne et d'Investissement, later to become the CCEI Bank. In Cameroon there is a tradition of *tontines*, micro-scale 'savings-and-loans' operations, in which participants save with a group of peers and borrow small sums from the group for operations such as digging a well or establishing a field of an improved crop variety. Since this system is essentially self-policing, rates of default tend to be low, less than 5%. It was already known that a relatively small injection of extra capital into these operations could generate tremendous benefits. The CGT decided to build further on this tradition, loaning through the CCEI to various groups at village level. The number of enterprises supported in this way grew rapidly and by 1999 the CGT programme was reckoned to be the third largest source of rural credit in Cameroon.

On the technical side, an initial experiment in which individual farmers were contracted to grow cassava cuttings proved scarcely more successful than relying on public institutions: the farmers found it more profitable to harvest and sell the roots. In due course, however, the CGT and other project partners found that a more effective strategy was to recruit women's groups to take on cassava multiplication as part of a normal business enterprise, using credit provided by the CGT. The amount of cassava production promoted by this means does not seem to have been evaluated, but IITA estimated that by 1990 some 11.9 million cuttings of improved varieties had been distributed in Cameroon through the combined efforts of various project partners and donors. Most importantly, cassava production and processing had become an integral and profitable part of the economy of southern Cameroon, bringing special benefits to women farmers and their families.

A mystery disease hits Uganda

In the confused aftermath of the civil war in Uganda, it is understandable that the destructive new disease epidemic in Luwero was initially misdiagnosed as a particularly severe outbreak of green cassava mite—a pest accidentally introduced from South America a few years earlier that had also decimated the national cassava crop and that caused superficially similar yellow mottling of cassava leaves. NARO researchers soon re-diagnosed the problem correctly as CMD, but there was no immediate explanation for the unprecedented severity of the outbreak of this long-endemic disease.

'The crisis came at the worst possible time,' remembers Dr William Otim Nape, now Deputy Director General of NARO but then leader of the root crops programme. 'Rebels fighting the new government had just forced us to evacuate our research station at Serere, in the east of the country, and we had to leave all our improved cassava genotypes and records behind.' In more peaceful days, Otim Nape had assembled at Serere an enviable collection of cassava germplasm, including a range of IITA disease-resistant varieties, and had begun making crosses to introduce the desirable characteristics into locally acceptable plant types.

Plant breeding, however, is a long-term undertaking and now urgent action was needed. Without access to the Serere collection, the researchers had few options available to them. A grant from the United States Agency for International Development (USAID) enabled them to proceed with a campaign to destroy all infected material and re-plant with 'Ebwanateraka', a local variety that was high yielding but had only low resistance to CMD. Crop sanitation had previously

The whitefly Bemisia tabaci, *vector of cassava mosaic disease.*

worked well in East Africa but the strategy broke down in the face of the increased disease pressure characteristic of the new epidemic. Within three months, the newly planted stems were totally infected by mosaic and the farmers still had nothing to eat.

So why was CMD causing so much destruction on this occasion? Otim Nape decided to expand his sources of expertise by bringing in Prof Mike Thresh, a virologist from the Natural Resources Institute (NRI) of the University of Greenwich, UK, thereby gaining access to a network of international knowledge. The first real breakthrough in understanding came when the expanded team of researchers identified the moving front of the epidemic, which was advancing southwards at a rate of about 20–30 kilometres per year and was associated with huge numbers of whiteflies. It appeared that the virus causing the disease was of a more virulent strain than had previously been identified and that the whiteflies were reproducing more successfully, though whether in response to the disease or to other changes in the environment was not clear.

To understand the virus better, Otim Nape solicited the help of Prof Bryan Harrison of the Scottish Crop Research Institute (SCRI). Together they analysed the deoxyribonucleic acid (DNA) of the virus and discovered that it was in fact a hybrid, resulting from the introduction of a fragment of DNA from the widely distributed African cassava mosaic virus (*Begomovirus*: *Geminiviridae*) into the genome of East African cassava mosaic virus. This was the first time such recombination had been documented in a geminivirus and the resulting virus subsequently became known as 'the Uganda variant'. 'Now we understand the molecular biology of CMD we can make diagnostic tools available to warn us of any new epidemics. So next time we will be better prepared,' says Otim Nape. The researchers also speculated that a further factor contributing to the severity of this outbreak was the drier seasons of the early to mid-1990s, which may have triggered the build-up of the whitefly vector, increasing the opportunities for infection.

The battle strategy

The nature of the virus only became clear at a late stage of the field campaign against CMD—and indeed some details of its molecular biology and epidemiology are still being elucidated. In the meantime, the NARO researchers were desperate for practical solutions. Otim Nape asked Mr Max Olupot, a technician, if he would be prepared to go back to Serere, where his family lived, and bring back any cassava material he could find. This was a dangerous mission, as the rebels were killing people found taking anything out of the area, but Olupot agreed, and sneaked back to the station. Amongst the dense stands of buffalo- and spear-grass that had invaded the trial plots he discovered a few surviving stems of seven cassava genotypes and brought them back to NARO's Namulonge Agricultural and Animal Production Research Institute (NAARI), where the root crops team was trying to re-group. News also reached researchers that a Serere farmer, Mr Otwani, had managed to retain a plot of Migyera, the Ugandan name for an IITA disease-resistant variety, TMS 30572, that had done well in Nigeria and Cameroon. On a second visit, Olupot managed to bring back a set of cuttings of this variety, carefully concealed in his *mukeka* (palm leaf) bag.

'From just four cuttings we grew as many as 29 plants,' says Otim Nape. 'Our research station became like a factory. After 18 months we had enough plants for trials to test for yield and resistance to CMD.' But the researchers still faced a daunting challenge: how could they multiply and disseminate enough stems to restore food production nationwide, especially with CMD still spreading rapidly, the research infrastructure destroyed and the extension service in disarray?

The NARO team adopted a threefold strategy. First, they abbreviated the normal process of developing and releasing resistant varieties. Instead of conducting several years of evaluation on the research station, the scientists sent promising clones for on-farm evaluation straight away. 'It was risky, but it worked,' says Otim Nape. By 1994, the high-yielding, resistant variety Migyera had been officially released to farmers, along with two others originating from the IITA breeding programme, Nase 1 (TMS 60142) and Nase 2 (TMS 30337).

The team's second initiative was to select target areas that were critical for cassava production and to approach Gatsby for help in funding the mobilisation and training of extension staff based in those areas. Although currently ineffective, the

A mosaic-resistant cassava variety (left) grows next to a heavily infected susceptible variety at Namulonge research station.

national extension service was well placed to undertake the work; it just needed more resources and better management—which could be supplied by researchers. The National Network of Cassava Extension Workers (NANEC) (see box, overleaf) was established under the supervision of the cassava team, who provided knowledge and training as well as logistical support such as transport. Farmers' and women's groups formed the core structure, and feedback was gathered through regular district meetings.

The third plank in the strategy was to accelerate the multiplication process. From a central multiplication block at NAARI, the researchers sent stems of resistant varieties for planting in additional multiplication blocks located in the target districts. They involved a wide range of institutions in the effort, including prison farms, disused research stations and schools, in addition to farmers. Between 1991 and 1996, over 100 million stems were distributed for planting.

The strategy for speeding up the multiplication process evolved as the cassava team gained experience. At first, the researchers chose institutions where they could maintain a high level of control over the process. But distribution from these sites was expensive, with a lot of the researchers' time spent on maintaining the plots and organising harvesting and despatch, and still far too slow. Gradually the team came to realise the advantage of multiplication on plots managed by farmers, individually or in groups. Once trained to collect data, the farmers were able to keep their own records, ensuring that on-farm research achieved far broader coverage for a lower input of researcher time. The groups were able to ensure that quality was maintained, developing a strong sense of ownership and pride in their work. They were also able to distribute materials through their own networks. And the on-farm plots provided a useful vehicle for training other farmer groups.

The researchers found they were also learning from the farmers. They became more aware of the need to select varieties with a wide range of different attributes. At Namulonge, farmers are now invited onto the research station to help evaluate and select promising varieties at a much earlier stage than was the case before the project. They decide what are the main criteria on which to base their selections and visit the station repeatedly as the crop grows, looking first at

NARO researchers at Namulonge continue to select mosaic-resistant varieties to suit local tastes. They maintain healthy stocks of the best varieties as a foundation for the dissemination effort.

A new institution restores production

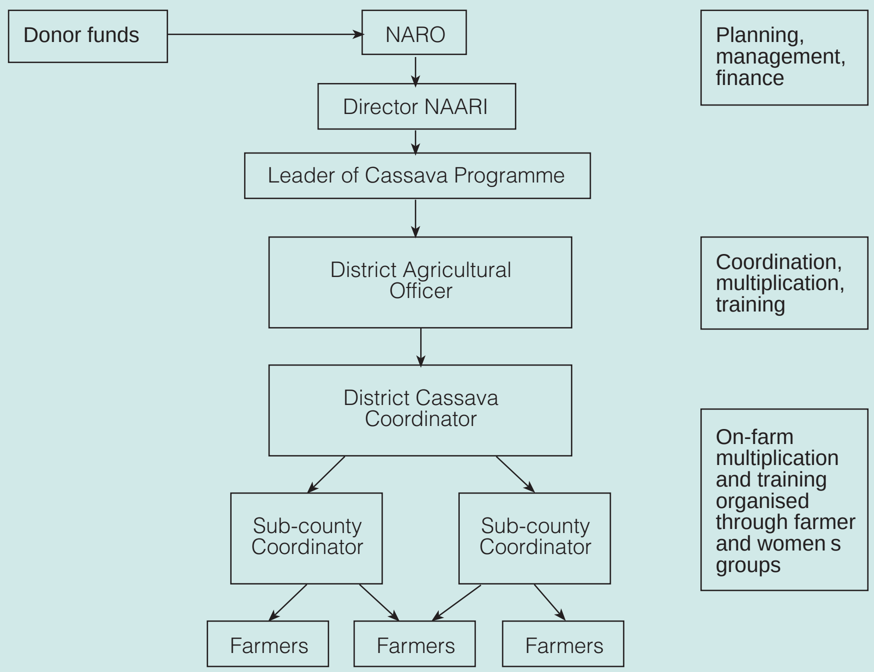
Over 3000 people are thought to have starved to death in Uganda as a result of the rapid spread of CMD and the devastation left in its wake. At the time of the epidemic, the Uganda Government extension service had more or less collapsed due to lack of resources, skills and motivation. Researchers had to come up with a highly efficient and effective multiplication and distribution strategy—and quickly.

The answer was the National Network of Cassava Extension Workers (NANEC), a novel researcher-managed extension strategy devised by Ugandan scientists but incorporating, on advice from Gatsby and IITA, elements of the strategies previously used successfully to disseminate improved cassava in Nigeria and Cameroon.

The scientists targeted six districts, representing the full range of CMD intensity. Through intensive training of the District Agricultural Officers, they were able to pass information—on how to control the virus and on good crop management—down the line to the farmers. Each team at district level was responsible for training other extension staff, chiefs, opinion leaders and farmers in its district. The teams were also responsible for conducting on-farm trials and for multiplying and distributing improved disease-resistant varieties, a process that was greatly speeded up by involving farmers' groups. Feedback to researchers, administrators and policy makers was also enhanced.

Between 1991 and 1996 over 35 000 farmers, extension agents and opinion leaders received training and by 1997 sufficient improved materials had been multiplied and disseminated to plant an estimated 100 000 hectares with the new varieties. The approach ensured that CMD-resistant varieties reached most parts of Uganda, quickly restoring production to its pre-epidemic levels. 'Once a certain threshold of contacts was reached, the process became self-perpetuating,' says Otim Nape.

The key ingredient explaining the success of the model was that researchers retained control of the funds for dissemination, ensuring that this task did not fall between the responsibilities of research and extension organisations. In addition, members of the research team were highly committed, intent on responding as best they could to a national emergency and imbued with a strong belief in the value of the technology they were disseminating. The farmers too were strongly motivated by the seriousness of the situation they faced.



germination qualities, then, after six months, at traits such as disease resistance and branching (low branches do not allow intercropping and make weeding difficult) and finally, after 12 months, at the harvest. The questions asked at this stage cover the whole spectrum of growers' and consumers' concerns. Can good yields be obtained without inputs? How big are the roots? How many? Are they easy to peel? Do they taste good raw? Are they suitable for traders to sell? Do they cook well? And do they taste bitter or sweet?

Another positive effect of the on-farm work has been the building of mutual trust between farmers and researchers. Initially farmers were deeply suspicious of the scientists, a feeling that was exacerbated when rebels hostile to the new government claimed that CMD was a form of biological warfare, that the new varieties were poisonous and that researchers carried the disease in their briefcases! In the aftermath of a long and bitter conflict, researchers have had to take time to build trust and form mutually beneficial relationships with farmers, especially in the more remote areas. Now that this effort has been invested, it will pay dividends for other crop improvement programmes and indeed for agricultural development in general.

Finally, the participatory training effort that accompanied the distribution of new varieties has left the farmers in a much better position to cope with new disease outbreaks or other challenges that may confront them in future. Farmers now know what causes CMD and how to control it. They are selecting healthy materials to plant and removing and destroying infected plants in the field, as well as using resistant varieties whenever the disease threatens (see box).

Preparing for the future

Unfortunately, this is not the end of the CMD story. As the crisis eases in Uganda, people in neighbouring countries are beginning to suffer. The moving disease front has destroyed large areas of cassava in western Kenya and is spreading rapidly through Tanzania, Sudan and the

The wise women of Vvumba

Mrs Dorothy Kabuye is soft spoken and deferential, but behind her mild manners lies a quiet determination: to make life better for herself, her children, the children who attend her school, and the 300 families who belong to the Vvumba Farmers' Group, which she leads. She well remembers the devastation CMD caused in Luwero District, an area where everyone depends on cassava for food.

'We were so desperate,' she says. 'When the disease came, we had no cassava at all. I remember how we used to sit together and weep. We felt we were failing as mothers when we couldn't feed or clothe our children. There was no money for medical treatment, and many marriages broke down because the women had to ask for money to buy flour. Their husbands would beat them and the children were always crying.'

It was in 1997, during one of these mutual lamentations, that the women decided they had to act. 'I remember as if it were yesterday,' says Kabuye. 'We were only six and felt we could achieve little with such a small group. So we decided to mobilise our neighbours. We went from house to house, until we had 37 people willing to take action.' With the group's backing, Kabuye plucked up the courage to visit the research station at Namulonge. 'We had seen that they were growing healthy cassava there, and we wanted to know how. I was so afraid—I had never been there before.' Kabuye returned with a single stem of the mosaic-resistant variety SS4. Not much to go on, but researchers also visited the group to explain the best way to multiply the material.

'We were amazed,' says Kabuye. 'We couldn't believe you could get so many plants from one stem and plant them so close together. Right from our grandfathers' time we had been taught that long stems would give a better harvest, and that the plants must be spaced so that the roots don't get tangled. After the researchers had helped us, we could get 10 times as many plants from one stem, and more than 1000 plants per acre. What a difference! We also thought that mosaic was brought by dust or pollution from the air. Now we know it is the whitefly who brings it and we can watch out for early signs of the problem and remove any sick plants.'

Dorothy Kabuye (right), leader of the Vvumba Farmers' Group, discusses cassava characteristics with NARO researchers.

Things are very different now in Vvumba. 'Our group has grown and all of them have enough to eat,' Kabuye says. 'Soon we may even have enough cassava to sell. We are also so much more confident. Our members are passing on their knowledge to other farmers and we are asking church and administrative leaders to preach about the new cassava and how to grow it.' The group are conducting on-farm trials as well as hosting multiplication blocks. They are helping researchers to select promising new varieties much earlier than before, visiting Namulonge regularly. One of the varieties they chose for their own village has been named 'Vvumba' in recognition of their efforts.

Democratic Republic of Congo. The good news is that, thanks to Gatsby's investment, the experience in Uganda has provided a successful model on which to base new campaigns of accelerated multiplication and distribution of disease-resistant planting materials.

NARO and IITA, again funded by Gatsby, are now working closely with colleagues at KARI to develop and adapt the NANEC model in western Kenya. This time the foundations for a more sustainable and cost-effective dissemination system are being laid earlier, by devolving most of the multiplication work to NGOs and farmer groups from the outset. The research system is still providing the initial planting materials and the technical information needed to multiply them, but a far greater degree of farmer participation is being sought. Farmers also have greater choice of variety: 14 high-yielding and disease-resistant genotypes are now available for evaluation and selection, and the farmers are being encouraged to evaluate these against a local check—work formerly regarded as the responsibility of the research team alone.

Involving farmers earlier in the process allows a greater number of traits to be evaluated, including root quality for different end uses. This selection for multiple attributes lays the foundation not only for increasing food security through higher and more stable yields but also for turning the crop into a more commercial enterprise that will raise farmers' incomes and create jobs in processing. 'The whole research process has been turned around,' says Whyte. 'It is now demand-driven rather than supply-driven. The next step is to involve market traders and industrial companies in the selection process.'

Keeping one step ahead

Uganda's root crops programme continues to evolve in response to changing conditions. As the worst of the CMD epidemic subsides, there are signs that some small-scale farmers are returning to their preferred local varieties. Breeders need to resume their effort to combine resistance to mosaic with the other traits that farmers want, taking into account such issues as intercropping, crop rotation and post-harvest handling. The variety Migyera, for instance, played a vital role in restoring productivity during the epidemic, but it is a bitter variety, ideal for traditional processing as practised in West Africa but ill suited to Ugandan tastes. The NARO team are still working closely with IITA, using quarantine facilities to bring in new materials and tissue culture to improve both the quality and quantity of planting materials still further. Links with the IITA–coordinated East African Root Crops Network ensure that a wider range of germplasm is becoming available for different environments, to respond to farmers' preferences and to prepare for an increase in demand for cassava as an industrial product.

A special effort is needed to develop new commercial opportunities for cassava. As cassava production has increased prices have fallen, benefiting poor urban consumers but reducing incomes for the small-scale farmer. 'We missed an opportunity here,' reflects Otim Nape. 'During the crisis, we probably could have obtained funds for developing varieties suitable for processing and

Dried cassava chips on sale at Nakasero market, Kampala. Improved production has led to lower farm-gate prices for roots, benefiting the urban poor but reducing farmers' incomes. New processing opportunities could boost incomes and employment.

with good post-harvest characteristics. Now it is more difficult to find money for this kind of work.' However, a new processing industry is beginning to emerge and there is great potential for starch exports if a supply of roots of suitable quality can be guaranteed.

Despite the sense that the high tide of interest in cassava research has passed in Uganda, the success of this high-profile project has had a longer-term impact on government policy towards agricultural research. Policy makers have passed much of the responsibility for technology transfer to NARO, ensuring the further development and application of the researcher-managed extension model. Another spin-off from the project is NARO's recently launched Outreach and Partnership Initiative. This aims to extend the coverage of on-farm research to all parts of the country, to improve the quality and relevance of the research and to build stronger links with a broader range of partners for the purposes of technology adaptation and dissemination.

Lessons of researcher-led dissemination

The Gatsby-funded cassava projects in Cameroon and Uganda challenged researchers to take responsibility for seeing the products of their work through to fruition in farmers' fields and local markets—and gave them the resources to do this. As Whyte notes, 'There was a gap between research and extension into which many promising technologies fell.' Gatsby sought to close that gap and placed confidence in the researchers themselves as the 'product champions' most likely to have the commitment to motivate colleagues in the face of difficulties and to draw partners fully into the development process.

Sustained support from Gatsby as the principal donor to these projects was an important element in their success, encouraging the commitment of project partners and allowing long-term goals to be set and achieved. The participatory approach, increasingly emphasised as the projects evolved from Cameroon to Uganda and now onward to Kenya, gave partners a sense of ownership of the development process and further reinforced their motivation. The full participation of farmers also helped to reduce the costs of the dissemination effort and increased the possibility of its becoming self-sustaining. The latest version of the dissemination system is an example of investment-primed, needs-driven, public–private partnership that deserves replication elsewhere in Africa.

These projects also demonstrate that investing in agricultural R&D, especially in improved varieties of basic food crops, can yield tremendous human benefits as well as saving millions of dollars in food aid. Although formal impact analyses have not been carried out, some indicative figures are available for the Uganda project: between 1989 and 1999 a total of US$ 2.5 million was invested in the fight against CMD; project staff estimate that the benefits of the project covered these costs by 1994 and reached US$ 91 million by 1999. This is the equivalent of obtaining an interest rate of 167% if the money had been invested in a bank. 'Probably the best investment in Africa ever!' claims NARO agricultural economist and current head of the organisation's cassava programme, Dr Anton Bua. 'The high rate of adoption was the key factor, and innovations such as NANEC and farmer-managed multiplication kept costs to a minimum.' Evidently the cost of developing the new technology in the first place—at least a decade of international effort by cassava breeders in several countries—has not been included in these figures. However, the success of the Uganda project illustrates what can be achieved when a major obstacle to progress can be clearly identified and efforts tightly focused on removing it.

'Gatsby's involvement in Cameroon and Uganda changed many people's attitudes,' says Whyte. 'As researchers we were trained to evaluate impact, not to create it, but now we see the dissemination of technology as part of an integrated R&D process. The real innovation has been institutional, not technological!' Yet the story of cassava in these two countries marks only the beginning of Gatsby's involvement in agricultural R&D in Africa. In the case of high-yielding, disease-resistant cassava, a good product was essentially ready for dissemination by the time Gatsby became involved and adoption was driven by acute need. The following chapters examine the evolution that has occurred as Gatsby has supported projects involving more complex technologies that require more participation by end users in the process of innovation.

Projects in brief

Disseminating high-yielding cassava in Cameroon

Partners: IITA and IRA (now IRAD).

Timescale: 1985–1990.

Aim: To increase the production of cassava in Cameroon by introducing high-yielding varieties.

Rationale: IITA's cassava improvement programme had developed vigorous new varieties, able to resist CMD and CBB, outcompete weeds and accumulate the greater part of their increased yield in less than one year, without increased inputs. These varieties were well suited to local processing into *gari* and had been readily adopted by farmers in Nigeria. Agro-ecological conditions and consumer preferences in southern Cameroon were sufficiently similar to suggest that the varieties would also be acceptable there. The main constraint to adoption, to be alleviated by the Gatsby project, was the need to organise a multiplication system to provide high-quality planting material.

Progress:
- The new varieties were widely adopted in four provinces of south-western Cameroon.
- Multiplication was sustained by women's groups (*tontines*) funded by the Cameroun Gatsby Trust.

Disseminating disease-resistant improved cassava in Uganda

Partners: NARO, NRI (University of Greenwich, UK), SCRI, IITA and CIAT.

Timescale: 1991–1998.

Aim: To improve the productivity of cassava farming systems in Uganda.

Rationale: Cassava is one of the most important food crops for smallholder farmers in Uganda and neighbouring countries. It can produce good yields with few inputs in poor soils and under drought conditions. The CMD epidemic in the late 1980s had caused enormous yield losses. Study of the disease and the release of improved varieties would restore production and food security.

Progress:
- Twelve high-yielding, resistant varieties were introduced.
- Resistant varieties were widely adopted in disease-affected areas of Uganda.
- A better understanding of CMD, including the molecular biology of the Uganda variant of the virus, was achieved.
- A model of researcher-managed extension was developed and tested.
- Farmers' and extension workers' awareness, knowledge and confidence were improved.
- The use of tissue culture was introduced to address quality issues.
- Cassava production now exceeds pre-CMD epidemic levels.
- The project was extended on a large scale in western Kenya, and also to areas of Tanzania, the Democratic Republic of Congo and Sudan.

3. More choice, more diversity: farmers participate in the selection of new rice and beans

Breeding for yield or sustainability

The timely resolution of the cassava crisis in Uganda showed how speeding up the multiplication and dissemination of high-yielding crop varieties can dramatically improve a nation's food security. Farmers, researchers and the development community learned a great deal from this experience. But to what extent can the experience be replicated in different crops and circumstances? If the principal challenge in disseminating improved cassava is to hasten the slow process of vegetative propagation, a key issue in improving the productivity of seed-propagated crops, such as beans and rice, is how to exploit and manage their inherently greater genetic diversity.

For thousands of years, farmers were the only plant breeders and seed merchants. By keeping the seeds of plants whose properties they preferred, farmers domesticated, improved and maintained the whole range of crops that we tend to take for granted today. In some cases they intentionally preserved diversity in their crops. The highland farmers of Central Africa, for example, have traditionally grown complex mixtures of common beans (*Phaseolus vulgaris)*, the mix of varieties being carefully managed to produce a crop that is fine-tuned to the ecology of their farms and whose yield is stable in the face of changing conditions. More often, farmers have selected one or two varieties that are well adapted to local conditions, but with each community preserving its own preferred varieties the net result has been the same: an almost bewildering kaleidoscope of crop diversity, maintained from season to season by the farmers themselves.

The advent of commercial plant breeding and the pressures of commodity markets have tended to reduce the diversity of crop varieties available to farmers (see box), as also has the strict statutory framework established in most countries to regulate the introduction of new varieties. National testing and registration procedures tend to be cumbersome and expensive to complete, obliging plant breeders to concentrate on producing a very few, high-yielding, varieties and leaving them little scope for developing varieties for niche markets, to cater for local tastes. In developing countries, however, farmers have often rejected the products of professional plant breeding because a locally important characteristic has been overlooked—perhaps taste, cooking qualities or suitability for intercropping.

Breeding for high performance

The erosion of crop genetic diversity—and the emergence of plant breeding and seed multiplication as distinct professions—began when a few farmers in the early nineteenth century started to breed crops for profit. Seed of successful varieties, in the first instance of wheat, became available in unprecedented quantities, no longer bartered with neighbours by the handful but offered for sale in bulk to anyone who could afford it. Varieties that offered significant commercial advantage, especially high yields, began displacing traditional land-races, which had usually been selected for moderate but stable yields. In developing countries, this process took hold in earnest during the Green Revolution. In the late 1960s the International Rice Research Institute, in the Philippines, released the first of a series of rice varieties that offered a quantum leap in yields and that, over the next quarter century, came to be grown over vast irrigated areas of Asia. The unprecedented productivity of this handful of 'miracle' rice varieties enabled food supply to keep ahead of human population growth in the region, but led to a sharp reduction in the diversity of rice varieties grown by farmers. By 1982, a single variety, IR36, was grown on 11 million hectares—8% of the area sown to rice in Asia. Thanks to the Green Revolution, people in Asia are now better fed, but scientists are concerned that the narrow genetic base of the region's crops leaves production vulnerable to pest or disease epidemics or to changing environmental conditions.

It is only recently that mainstream plant breeders have begun to embrace participatory varietal selection (PVS), a strategy that fully involves end users (including farmers, processors and consumers) in choosing locally from a wide range of promising varieties, with the explicit aim of preserving a diversity of genotypes while also achieving high yields. Maintaining crop diversity in this way not only makes it possible to satisfy local needs and preferences but also preserves the ability of the farming system to adapt to change. Gatsby, along with other donors, has helped farmers in villages across Nigeria and Ghana [1] to identify their preferred rice varieties from a diverse set of new materials developed or introduced by the West Africa Rice Development Association (WARDA). Through PVS, farmers who are largely excluded from conventional plant breeding are brought back into the selection process as full partners.

Meanwhile, across the continent in Uganda, Gatsby funding is helping bean farmers not only to choose the varieties that answer their needs but also to take charge of the next step in the R&D process, which is to multiply good-quality seed of these varieties. Indeed, Uganda's NARO is finding that participatory approaches are helping researchers and farmers to work together to tackle a whole range of constraints—from choosing the most appropriate varieties, through managing pests, diseases and soil fertility during production, to storing the harvest and marketing seed and food products. In the process, the researchers are learning to respond to market forces, which are often the most potent influence driving changes in the needs expressed by farmers.

Nigerian farmers help to select 'new rice'

Rice breeder Dr Monty Jones of WARDA is one of the new generation of plant breeders who have turned enthusiastically to PVS. Raised in a village in West Africa, where he experienced the harsh reality of 'food insecurity' at first hand, Jones is single-minded in his commitment to the mission he embraced when he set out on his scientific career: to apply the tools of modern science to the problems of small-scale rice farmers across the region of his birth. 'Embryo rescue' is one of a family of tissue culture tools that help plant breeders to save the progeny of the initial crosses between plant species that would not otherwise be able to produce viable seed. In 1991, Jones and his colleagues began using embryo rescue to cross African rice, *Oryza glaberrima*, and Asian rice, *Oryza sativa*, opening the way for a breeding programme that would combine the best characteristics of the two species.

African rice is a tough plant. It grows vigorously, even on poor soils, producing numerous stems and wide, drooping leaves that compete successfully against the weeds that either overwhelm its Asian relative or else condemn farmers, especially women, to the backbreaking drudgery of endless weeding if they want to harvest a reasonable crop. African rice is also more resistant to pests and diseases. Unfortunately it has weaknesses too: its tall stems tend to buckle under the weight of grain and the seed heads shatter when they are ripe, dropping the seeds from the plant. This is the natural behaviour of a wild grass but it costs farmers precious grain—grain that they can ill afford to lose since African rice already tends to yield less than its Asian relative.

Under the relentless logic of the market, rice farmers in Africa have responded to increasing demand by abandoning their traditional varieties and adopting the high-performing Asian version of the crop. 'Rice used to be a rich man's food,' explains Dr Olu Osiname, leader of WARDA's team in Nigeria. 'Now you will find it in every market, alongside more traditional foods such as *gari*, and the school children line up in the morning for rice to take to school for their meal.' Osiname quotes WARDA figures showing that the consumption of rice in Nigeria and elsewhere in West Africa is climbing inexorably, while local production, though increasing, has been unable to keep up. 'The imports drawn in by increasing demand for rice cost West African countries almost US$ 1 billion a year in foreign exchange, money we could save for other valuable uses if we could grow

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[1] Efforts to introduce the new rices in Ghana are not as far advanced as in Nigeria. However, PVS trials have been established in two regions and now involve at least 350 farmers. WARDA's national partner in Ghana is the Council for Scientific and Industrial Research (CSIR).

more of the crop ourselves.' The rice varieties that WARDA is developing should help to boost local production and improve the lot of poor farming families and consumers throughout the region.

The new varieties—dubbed NERICA, **NE**w **RI**ce for Afri**CA**—combine the vigorous weed-suppressing, pest- and disease-resistant characteristics of the African plant type with the larger heads and non-shattering grain of the Asian species. The plants are taller than Asian rice, making them easier to harvest by hand, and their grain contains some 2% more protein than that of either parent. Despite a shorter growing period, yields are better too. Almost half the rice in West Africa is grown not in intensively managed irrigated paddy fields, as in much of Asia, but under rainfed conditions, where yields at present are often less than 1 tonne per hectare. According to Jones, the new varieties can produce as much as 2.5 tonnes per hectare with low use of inputs and up to 5 tonnes or more with just a little more fertiliser. And the drought tolerance conferred by the African parent vastly increases the area over which rainfed rice can be grown. Osiname estimates that the rice-growing area of Nigeria can be extended by some 20–30% using the new varieties, a potential that will have to be realised if the country is to meet growing demand.

At the core of the PVS approach being used by Jones and his colleagues is a three-year rolling programme, which moves from village to village, drawing in more rice farmers and boosting production as it goes. In the first year of the programme, a 'rice garden' of some 20 or more varieties is established, including both previously released varieties, which are familiar to farmers, and the new WARDA varieties (both those based on the *sativa* × *glaberrima* crosses and other promising conventional selections). The 'garden' is preferably hosted by an enterprising farmer but is sometimes planted on a research station or other public land. Whatever the location, a group of nearby farmers is invited to visit the trial twice during the first growing season, first as the grain begins to fill and then again at harvest. Working side by side, researchers, extension workers and farmers evaluate the whole set of materials on offer—not just for yield but for many other criteria too, especially those the farmers themselves decide are most important. 'These are real experiments for us, as

A woman in Abeokuta market, in south-western Nigeria, sells rice—in this case imported—alongside traditional local staple foods.

well as for the farmers,' says Osiname. 'We try to choose a range of materials that we believe are well adapted to the general ecology of the area. But we do not know in advance which varieties will both flourish and satisfy local farmers' tastes.'

Based on the first year's evaluation, the farmers choose the five or six varieties that appear best suited to their needs and to local conditions. They take away samples of the seed and, in the second season, try it out for themselves. The research and extension team work with the farmers to decide on the most appropriate sowing dates and the regime of inputs—fertiliser and pesticides—best suited to local conditions, so the farmers learn at first hand how to manage the crop so as to maximise yields. In the third year, the one or two best varieties are planted and evaluated on a larger scale by the pioneering farmers in the group, while significant quantities of seed are generated to offer to yet more farmers in the neighbourhood. Meanwhile, the research and extension team move on to identify new villages and farmers with whom to launch the programme. Because of unfavourable weather, outbreaks of pests and diseases or other adverse circumstances, the selection cycles do not always go according to plan. However, the participants work together to overcome such hurdles, emerging strengthened by the experience.

The success of a project like this depends critically on drawing together the right partners, since only then will the necessary expertise and enthusiasm be assembled and generated. The National Cereals Research Institute (NCRI), with its base at Badeggi in the heart of Nigeria's rice country, has been the lead national institution since the launch of the Gatsby-funded rice project in Nigeria in 1998. The project gained impetus when WARDA's Nigeria-based researchers also took a direct hand in establishing PVS trials. Three years on, the project is now active in 14 states of the Federation and has reached over 1000 farmers. In each state, the plant breeders team up with officers of the appropriate state-run ADP and with researchers from the relevant agricultural university. The involvement of these partners ensures that farmers will continue to receive technical support while the programme of varietal trials moves on. It also encourages the 'spill-over' of participatory methods into work on other staple crops.

Besides this broad participation by national institutions, another encouraging sign of the project's success is that National Seed Scheme personnel have also become involved in the PVS process. This link should pay dividends in future by encouraging the timely certification of the rice varieties selected by the farmers (see box).

Empowering farmers to solve their own problems is an important aim of participatory research. 'We have graduated,' say the rice farmers of Ifote-Egbeda village. 'Now others will come to us to learn.'

Fast track to varietal certification

Conventional procedures for the official registration of new crop varieties are often slow and expensive, imposing a severe constraint on the choice of new materials reaching farmers. After plant breeders have satisfied themselves as to the performance of the best new materials under a range of conditions, the materials are tested all over again, usually over several growing seasons and at a number of sites in different agro-ecological zones. This costs additional time and money, which must come either from the plant breeding enterprise or, more often, from the public purse. Governments like to undertake such testing themselves, as an assurance to farmers that a variety receiving the official 'seal of approval' implied by registration has been tested impartially and really can be expected to perform as advertised. The disadvantage is that very few materials can be processed through this system.

Nigeria is one of many African countries that has followed this cautious approach in the past. However, when officials from the national seed service were invited by WARDA and its partners to take part in their participatory trials, they were so impressed by the thoroughness of the exercise that they are considering building the results into their own testing and approval procedure. The multi-partner nature of the exercise and the ownership of the individual trials by farmers help to ensure that the trials are indeed impartial and they evidently cover a very wide range of sites. The participatory trials are not seen as a substitute for official testing but as a supplementary source of data. Combining the results from the two sources should speed up the approval process and allow more varieties to be registered. Best of all, by the time official registration is forthcoming, at least some farming communities will already have adopted the new varieties, giving dissemination a head start.

'This project is revolutionising the way new varieties are introduced in Nigeria,' says Dr A.Y. Adeoti of the University of Agriculture, Abeokuta. 'Previously, the first that most farmers heard of a new variety was when the radio announced that they could go and buy it at the agro-service centre. After so many disappointments, many farmers would not even bother to go. Now they are seeing and testing new varieties in their own fields—and the best varieties are already spreading from farmer to farmer by the time registration comes through.'

Promoting innovation in an unstable policy environment

Rice requires considerable processing before consumption: first threshing and hulling to remove the husks, then milling to remove the seed coat; and in between it can be parboiled, to enhance the taste and reduce the number of grains broken in milling. In West Africa, hulling and parboiling are usually done by hand, on farm, whereas milling is done by machines, which may be communally owned or in the hands of private millers. As pointed out in Mosley's policy study, the off-farm employment opportunities provided by operations such as milling can greatly increase the impact of introducing new varieties on livelihoods. However, if cheap imports undercut the local product, the extra costs associated with processing and marketing farm surpluses (which include labour, items such as firewood for parboiling, and transport) tend to discourage farmers from growing more productive rice varieties.

In Nigeria a government committed to free trade—and perhaps keeping a wary eye on the well-being of a restless urban electorate—allows imports of inexpensive rice from the USA and Thailand, thereby undermining the viability of WARDA's efforts to stimulate local production. In recent years it has been difficult, if not impossible, for many of Nigeria's farmers, especially those in the hinterland of the large coastal cities where the imports arrive, to make a profit from producing rice. In the village of Ifote-Egbeda, north of Abeokuta, farmers loved the new varieties introduced by the project but would grow them only for consumption within their own community. Despite benefiting from some of the lowest fuel prices in the world, the farmers had regretfully come to the conclusion that it was not worth hauling their abundant harvest to the nearest commercial market, some 25 kilometres away.

If imports are restricted or tariffs are imposed, this will tilt the playing field in favour of domestic rice producers. Some of the farmers would like to see preferentially targeted credit or other forms of subsidy to help them to establish (or re-establish) local rice production (see box). Indeed, a strong case has been made by Mosley and other analysts for providing access to credit in parallel with any attempt to introduce agricultural innovation, to help farmers cope with the extra risks of adopting more productive technologies. However, there is a fine dividing line between interventions that help to overcome temporary obstacles and those that distort markets, increase dependency and ultimately work against sustainable increases in productivity.[2]

Would subsidies help?

Nigeria's savvy farmers are well aware of the politics and economics of rice production and of the issues surrounding imports, which have been periodically banned in the past, drastically improving the prospects for domestic production. 'If Gatsby would provide a loan to buy a milling machine, that would make it worthwhile to grow rice,' says the spokesman for the rice farmer research group at Ibogun-Olaogun village, between Abeokuta and Lagos. 'And the ADP should make good on its promise to help organise transport,' adds another member of the group. 'The government has proposed to re-introduce fertiliser subsidies. That would make a big difference,' volunteers a third.

Subsidies of various kinds may well be justified in the short term in many countries of West Africa, especially since the competitors of these countries are often able to sell into these markets only because they use subsidies themselves.

Fostering a spirit of enterprise and a determination to tackle problems locally is perhaps especially important in a society like Nigeria's, where abundant oil revenues in the 1980s encouraged some sectors of the economy to become overly dependent on central government intervention and hand-outs. The communal approach to problem solving encouraged by PVS teaches useful motivational skills and empowers rural people to address development challenges. As such it has value as a development tool, even if the primary objectives of the projects in which it is used are, for whatever reason, not immediately achieved.

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2 Nigeria and other West African countries have alternately imposed and lifted tariffs or outright bans on the import of rice, maize and other food crops several times over the past 25 years. Since this report was written, the Nigerian government has imposed a tariff of 100% of import prices together with a further levy of US$ 20 per tonne, which will be used to fund research and infrastructure for national rice production.

Beans for all seasons

By the time Gatsby joined in to support their efforts, Uganda's bean breeders had already gone through the chastening experience of having their 'best' conventionally developed products rejected by farmers. It was several years since they had turned to participatory methods to redeem the situation.

In highland areas throughout Eastern and Central Africa, beans are an important part of the economy and are eaten twice a day, every day, by many rural people. A highly adaptable crop with a growth cycle of only 70–90 days, beans can be intercropped with many starchy crops, including banana or cassava in addition to cereals. Consumed with these foods, beans provide the main source of dietary protein—along with iron, vitamin B and folic acid—for people who do not have access to adequate supplies of meat or fish.

Bean research in Uganda dates back to the 1960s, when the high incidence of malnutrition among children prompted the Ministry of Agriculture to initiate a bean breeding programme. The bush variety K20 was released in 1968 and is still widely grown throughout East Africa. However, since then progress has come painfully slowly, and productivity remains low or has actually fallen in many areas. 'So many diseases and pests thrive on beans,' says Dr Michael Ugen, Leader of the National Beans Programme. 'Problems of root rot, bacterial blight and insect attack, together with small farm sizes, lack of crop rotation and declining soil fertility, mean that yields are universally low. In some areas, people are giving up growing the crop entirely.'

Clearly, a concerted effort was needed to address this wide range of constraints. As its partner in this effort, NARO turned in 1983 to the Centro Internacional de Agricultura Tropical (CIAT), which has the mandate for international research on beans. Although its headquarters are in Colombia, CIAT has long pursued a decentralised research policy, with small teams based in numerous countries around the world, ready to work with national researchers and to respond to local needs. Consistent with this policy, CIAT's bean breeders have embraced the principles of preserving local land-races and of producing the widest possible range of new materials, thereby catering to the specific needs and tastes of local growers and consumers as well as offering the benefits of modern plant breeding in terms of improved yield and broad adaptation to stresses. CIAT has also been a pioneer in developing and using farmer participatory research methods, both for crop breeding and to tackle natural resource management problems. In short, NARO and CIAT were ideal partners for the task at hand.

NARO's National Beans Programme began on-farm bean variety evaluation trials in 1986, emphasising high-yielding varieties with resistance to major diseases and insect pests. Over 50 varieties were tested but, despite high yields, many were rejected by farmers. From 1992 onwards, NARO adopted a more participatory approach, explicitly recognising that it is not just yield and disease resistance that influence farmers' choices but that local tastes and compatibility with local farming systems can be equally compelling (see box).

The first varieties derived from the collaboration with CIAT—K131 and K132, released in 1994—received mixed reviews. Beans represent an important source of income for an increasing number of small-scale farmers in the highlands of East Africa, contributing 7 to 9% of household income in some areas, so a variety must be easily marketable if it is to be widely adopted. The variety K132 was readily accepted by consumers and farmers as it was not only high-yielding but also gave a familiar type of large red bean (similar to K20) that fetches a good price in the market. Although K131 had better disease resistance and was therefore accepted for its contribution to household food security, it did not help to generate significant income as it was a Carioca-type bean—popular in Brazil but unfamiliar to consumers in East Africa. The lack of demand meant that it could only be sold at a low price. In addition, it takes a long time to cook, a severe constraint in the many areas where fuelwood is scarce (see Chapter 5, p. 39).

'These were the first new releases for 26 years,' says Ugen. 'But uptake was slow. We needed to understand not just how to speed up the transfer of technology but also how to target new varieties to specific communities so as to achieve maximum impact.' Gatsby responded to this challenge by funding a project that aimed to help researchers understand the problems faced by farmers, involve farmers more in varietal selection

Understanding diverse choices

Markets throughout Africa display a bewildering variety of beans. Urban populations are more likely to experiment and try different types, but in more rural areas it is much more difficult to persuade people to grow or buy unfamiliar beans. And it is not just the appearance that can put them off. Taste, cooking time, growth habit, traditional methods of preparation and many other factors make a difference to acceptability. For example, in Uganda's central and eastern region, a Carioca-type bean (a small, light brown bean, immensely popular in Brazil) had higher yields than the local variety but was rejected because its growth habit did not allow it to be intercropped, it did not store well or keep well after cooking and it did not make good *katogo* (bean soup mixed with banana). In Apac District, in central Uganda, small beans are preferred as they can be more easily scooped onto a slice of millet bread. And many people like to cook their beans and banana in the same pot, so red or pale coloured beans are more acceptable than black ones, as banana turns black while cooking and most people won't eat an entirely black dinner! But in other areas, black beans are perceived as an especially long-lasting, energy-giving meal. In the south of the country, two growing seasons per year are possible, so a short time to maturity is a real advantage, but storage may be difficult due to a high incidence of bean weevils. Add to all this the fact that different varieties grow best in different climatic conditions, and selecting which varieties to make available can give researchers a real headache!

At Kalere market, just outside Kampala, various different types of beans are offered for sale.

and the demonstration of new varieties, accelerate the multiplication and distribution of improved seed, and train farmers and extension workers in improved crop management technologies.

'This project built on our previous experience,' Ugen continues. 'It was the logical way to go.' For NARO, the experience of multiplying cassava in response to the CMD epidemic had underlined the importance of involving farmers. Now the organisation's scientists set out to test and disseminate bean varieties through a modified form of the cassava multiplication system. In so doing they got off to a flying start in the areas that also grow cassava, where they already had a good network of contacts. The pilot phase began in 1997 in Apac District and was extended in 1999 to parts of Masindi and Mpigi Districts—all areas where the cassava project had already been active. By building on existing farmer contacts and proven administrative and management procedures, the team was able to achieve a broad and rapid impact.

To multiply the new beans, the researchers introduced a 'seed loan' system, whereby farmers were given 2 kilogrammes of seed initially and had to return the same amount after their first harvest. In addition, they were asked to give away seed to their neighbours. As in the case of cassava, a variety of institutions including schools and prison farms were involved in multiplication.

Besides asking the farmers to evaluate different bean varieties, the team have helped them experiment with intercropping and the use of stakes from fast-growing leguminous trees as a support for climbing beans. This additional component of the project, funded by Gatsby at NARO's request, is a further example of how flexibility in defining the research agenda can pay off. Introduced to the region from Latin America in the mid-1990s, climbing beans have proved immensely popular with farmers because they are space-savers, offering more yield per unit of land and so freeing up room for other crops.

Also under the project, farmers, extension agents and community opinion leaders attended training courses to help them improve their knowledge of production technologies, post-harvest handling, soil fertility management, integrated pest and disease management, on-farm research methods and different ways of cooking and preparing beans.

Researchers too learned from the project, because the close links forged with farming communities enhanced their understanding of local constraints to growing and marketing beans. They confirmed and built on their earlier positive experiences of participatory approaches, seeing for themselves how these ensure the selection of varieties that are well adapted to the local environment and farming system and how they can help to formalise the process of assessing consumer preferences, ensuring that fully acceptable varieties are introduced.

A formal impact assessment has not yet been undertaken, but the project's results are already very encouraging. In Apac District, where activities began with 20 farmers, a total of 1500 had access to the improved varieties after only one year. The total across the three districts now exceeds 6000 farmers. The yields of the new beans are nearly always higher than those of the local types, and the indications are that their introduction has had a positive impact on food security, nutrition, farm income and social welfare. Certainly, anecdotal evidence suggests that the livelihoods of individual farmers have been transformed (see box).

Better bean harvests

Mr Sam Opio is proud of his new ox-plough, but even more proud of the two oxen he has just bought. 'These new beans have made so much difference to me,' he says. 'Five years ago I bought half a kilo of special beans (Nabe 2) from my neighbour; those beans have changed my life.' Opio re-planted his entire first crop of 7 kilogrammes, harvesting an impressive 600 kilogrammes in the second year. For the first time, he had enough beans to feed his family and some extra to sell for cash, enabling him to pay medical bills and school fees. In the third year he re-planted 10 kilogrammes and again harvested over 600 kilogrammes, selling half and keeping half to eat. 'Two years ago I bought the plough, and last year I could afford these two oxen to pull it,' he says. 'Now I have solved my labour supply problem I can increase the amount of land I put to beans and other crops. I feel much more positive about the future, especially about my chances of feeding my family. And I am sending my children to school.'

Beans from a bumper harvest are spread out to dry in the sun.

Public spending and the quest for sustainability

In Uganda, a government that is committed to market liberalisation has set its sights on full privatisation of the seed and agricultural inputs sector and is considering at least partial privatisation of agricultural advisory services. Where does this leave NARO's researcher-led efforts to revitalise the country's bean production? The strict limits on public funding call into question both the effort to establish a quality seed supply system for small-scale farmers and the use of participatory methods for varietal selection and farmer training.

For small-scale farmers, regular access to good-quality seed of new bean varieties at an affordable price continues to be problematic. In Eastern and Southern Africa in general, the commercial seed industry has found it uneconomic to supply the small-farm sector with seed of this slow-to-multiply, self-pollinated crop. The public-sector seed service has, in some ways, been equally unsuccessful, producing only limited quantities of certified seed of a few, mainly commercial, varieties. Stimulating the establishment of a self-sustaining, farmer-led system for multiplying and distributing the seed of a wider range of improved varieties is therefore an important element of the Gatsby-funded project.

Uganda's NANEC system as originally conceived (see box, p. 12) is publicly managed and must be financed either by government or by external donors, raising questions about the economic sustainability of this approach. The adaptation of the model so as to place increasing reliance on farmers is a big step in the direction of sustainability, but support from outside the farming system is still needed, especially for training and demonstrations. A further element that can help to contain public costs and increase cost-effectiveness is the involvement of NGOs. In Mpigi, where NGOs participated particularly strongly, adoption was more rapid than in other districts.

Networking among organisations that share common problems is also a strategy that can help to share the costs of R&D efforts—though the transaction costs of operating the network do have to be taken into account. NARO researchers are active participants in the CIAT-coordinated Eastern and Central Africa Bean Research Network (ECABREN), a formal association of national bean research programmes involving researchers, university staff, NGO workers and representatives from the private sector. The network has already helped to spread new bean varieties throughout the region and has played an important role in scaling up activities by disseminating information. Through ECABREN, researchers in 16 countries are able to work together to identify common problems, set research priorities, exchange results, build local problem-solving capacity and improve the availability of funds. However, the essence of the PVS process is that selections must be made locally, so in this specific area networking is no substitute for local action.

One of the largest cost components in the present NARO system is the initial free distribution of seed under the seed loan scheme. 'I am convinced that seed should be sold and not given away,' says Dr Roger Kirkby, CIAT's Africa Coordinator. 'Transaction costs for a seed loan system are high, and farmers are more motivated to look after their crop if they have invested money in it.' An alternative strategy might be to organise the marketing of small packets of seed through a range of outlets, particularly those visited predominantly by women, which include rural shops, health clinics and women's groups. Such a strategy could be particularly effective in improving access to new varieties in remote areas beyond the reach of the formal seed system. Some of the money raised by marketing seed in this way could be ploughed back into the task of maintaining seed quality—an area in which continuing public-sector involvement appears desirable, at least for the time being. Yet another model is offered by the local agricultural research committees pioneered by CIAT in Latin America.[3] Many such committees started by conducting research on new crop varieties, usually with seed money and outside technical support, but then developed into self-sustaining small businesses marketing the seed of those varieties found suitable for the local environment. However, this model has yet to be proven in Africa.

A wider question hangs over the cost-effectiveness of PVS compared with the conventional methods of developing and disseminating new crop varieties. The close relationships with farmers that are characteristic of PVS are time-consuming and expensive to develop, but Kirkby for one is in no doubt about their value: 'Without farmer participation early on in varietal development you can waste years going down the wrong

New rice varieties compete vigourously with weeds and reduce the drudgery of weeding for farm families.

[3] See: Ashby et al (2000). Investing in Farmers as Researchers: Experience with Local Agricultural Research Committees in Latin America. CIAT Publication No. 318. Cali, Colombia.

road.’ By ensuring that only those varieties with a good chance of being accepted reach the stage of formal testing and release, much researcher time and effort is saved. And by increasing the choice of varieties available to farmers at an earlier stage, the NARO–CIAT team has been able to improve adoption rates markedly, to levels far higher than those achieved in conventional extension systems. Since the first two varieties resulting from the collaboration were released in 1994, another 13 have become available—and farmers are currently evaluating many more.

Clearly, in Uganda and Nigeria, as in many other African countries, the on-farm varietal selection and seed dissemination system needs to evolve further if it is to become an economically sustainable market-driven system based on private enterprise. In the meantime, the researchers who are Gatsby’s partners in the field are convinced that participatory methods play an indispensable part in agricultural innovation. They say that farmers who have taken part in participatory research are subsequently more willing to experiment on their own account and have gained confidence in their ability to solve problems in the future. Farmers who have adopted new varieties of beans or rice have been more willing to try improved varieties of other crops, such as sweetpotato, maize and banana, as well as novel approaches to managing them (see Chapter 4, p. 33, for a discussion of banana pest management). This R&D model evidently helps to increase crop diversity, as well as incomes and food security, providing another good reason for finding the necessary means to pursue its application.

Projects in brief

Testing and disseminating New Rice for Africa

Partners: WARDA and NCRI (Nigeria); WARDA and CSIR (Ghana).

Timescale: 1999–2002.

Aim: To raise rice production and improve livelihoods by introducing to farmers a range of high-yielding, stress-tolerant rice varieties.

Rationale: Rice consumption is increasing in West Africa but local production is unable to meet demand, due partly to low yields of Asian rice genotypes under prevalent low-input conditions. New rice varieties, including those derived from *O. sativa* × *O. glaberrima* crosses, offer greatly increased yields under both intensive and low-input, rainfed regimes. PVS allows farmers to select varieties tailored to local conditions and needs.

Progress:
- In Nigeria, PVS trials have been established at sites in 14 states, involving more than 1000 farmers.
- In Ghana, PVS trials have been established in two regions, involving at least 350 farmers.
- Several new rice varieties are being enthusiastically adopted.

Transfer of improved bean production technologies to farmers

Partners: CIAT and NARO (Uganda).

Timescale: 1997–2002.

Aim: To alleviate poverty and malnutrition through improved bean productivity.

Rationale: Beans are an important source of protein in Uganda, especially in the diet of the poor. Yields remain low due to poor soil fertility and the high incidence of pests and diseases. Increased bean productivity will improve nutrition and help alleviate poverty, particularly among women and children.

Progress:
- Over 21 000 kilogrammes of improved seed have been distributed to over 6000 farmers.
- The adoption of new varieties increased from 7 to 45% of the total area cultivated to beans in Mpigi District over the period 1998 to 2001.
- Adoption is also spreading to non-participating farmers and new areas.
- Multiplication activities involving individual farmers, farmer groups, NGOs and other institutions are under way.

4. Research clears the roadblocks:
overcoming successive obstacles to the deployment of improved banana and plantain

Root causes

Mr Akilleo Mukiibi had all but given up eating his favourite food. Like thousands of other small-scale farmers in Bamunanika District, 40 kilometres north of Kampala in Uganda, he had always grown a variety of food and cash crops to feed his family, earn an income and spread the risk of a bad harvest. An acre of coffee bushes provided his main source of cash, but the family's preferred dish was *matoke*, prepared from steamed, mashed bananas. The yield of Mukiibi's banana orchard, however, had declined drastically in the face of pest and disease attack, exacerbated by inadequate management. 'The plants were yielding less and less and I was beginning to think we could no longer grow banana here,' he says. Even attempts to establish new orchards were frustrated, because the soil-borne pests were carried along with the banana suckers used to establish the new plantings. 'The pest problem meant that a new banana plot would only last about one year, and the bunches were so small they hardly provided one meal for the family. We could eat *matoke* only on Sundays, and there was nothing left over to sell.'

Mukiibi's experiences are mirrored almost throughout the banana-growing areas of Eastern and Central Africa. Banana is the staple food and principal source of carbohydrate for around 20 million people in this region's highlands, while both banana and its close relative, plantain (both are members of the *Musa* genus), are an important part of the diet for many more people, perhaps another 30 or 40 million, in the region's tropical lowlands. Almost everywhere, the crop is grown on small farms for home and local consumption, surplus fruit being sold to neighbours or in nearby market towns to provide a small but vital source of additional household income. Bananas and plantains are particularly valuable in sustaining families through times of hardship, when coffee or cocoa prices fall or when annual crops such as beans or maize fail. In densely populated high-rainfall areas, such as the highlands of Eastern Africa, smallholder banana plantations play a special role because this perennial crop helps to protect fragile soils from erosion.

Small-scale producers in both highland and lowland systems have experienced falling yields over the past 20 years or more—a syndrome researchers have come to call 'banana decline'. Diseases, pests and sub-standard management all contribute to the decline. From the 1980s onwards, the leaf disease Black Sigatoka, caused by the fungus *Mycosphaerella fijiensis*, has spread widely, sometimes causing spectacular losses, while an older epidemic of the soil-borne Panama disease, caused by another fungus, *Fusarium oxysporum* f. sp. *cubense*, continues to take its toll on certain varieties. Banana weevil (*Cosmopolites sordidus*) and nematodes (such as *Radopholus similis*, *Pratylenchus* spp. and *Helicotylenchus multicinctus*) attack the roots of the crop, reducing vigour and fruit yield but, above all, causing the plants to topple over under the weight of their fruit. Plants that are well watered, weeded and supplied with organic matter to maintain soil fertility can, to a considerable extent, resist the attack of pests and diseases, but the region's hard-pressed resource-poor farmers are seldom able to provide this level of management. Plantations that used to maintain yield levels over decades now experience steeply declining yields, year by year. Yet, as population pressure increases, there is precious little new land for planting—and re-planting on land that was previously under bananas simply perpetuates the problems.

Faced with what looks like a no-win situation, many farmers have simply abandoned banana production. However, a series of projects funded by Gatsby and other donors is systematically addressing the complex causes of banana decline. The projects range across the R&D spectrum—from understanding the nature of viral diseases, through the development of virus diagnostics and new disease-resistant *Musa* varieties, to the adaptive on-farm research and institution-building needed to test and disseminate the new varieties and the better management practices required to keep them healthy. This last project, with its dual focus on new varieties and management practices, is an ambitious effort to revitalise banana production in central Uganda by educating farmers to replant their bananas on land that has previously either been fallow or planted to other crops. The signs are that this project is having an immediate impact on livelihoods. This positive outcome, however, depends on the efforts already invested by researchers, and the donors who support them, in removing the obstacles, both technical and organisational, along the road to recovery.

Akilleo Mukiibi is proud of his plantation of Mpologoma, an improved local matoke *banana that is helping to restore the fortunes of his family. He has become a 'trainer farmer', selected by his peers to learn about new varieties and practices and to share the benefits of this knowledge with others.*

An international breeding effort

The public-sector resources allocated to Africa's small-scale banana and plantain sector are modest. In the mid-1970s, IITA embarked on a programme to support the limited research conducted at national level by breeding improved, disease-resistant varieties. Initially, the programme focused mainly on plantains, the work being conducted at the Institute's research station at Onne, in south-eastern Nigeria. However, the programme's scope was considerably broadened, to include the breeding of highland cooking bananas and the development of better management practices, when a multidisciplinary team was established at IITA's Eastern and Southern Africa Research Centre (ESARC) in Uganda, in the mid-1990s. Among the many institutions worldwide working on banana at the national and regional levels, the Centre Régional de Recherches sur Bananiers et Plantains, in Cameroon, responds to the needs of small-scale producers throughout Africa, while the Fundacion Hondureña de Investigación Agricola (FHIA), in Honduras, has produced varieties and research results of value in Africa, even though its primary responsibility is to serve commercial producers in Central America. Indeed, it is a variety from this source, FHIA 17, released in Uganda as Kabana 3, that has become a central component of this country's banana rehabilitation effort.

Promoting the exchange of knowledge and materials among *Musa* researchers around the world is the mission of the International Network for the Improvement of Banana and Plantain (INIBAP), a programme of the International Plant Genetics Resources Institute (IPGRI). INIBAP was created in 1985, largely in response to the threat posed by the spreading epidemic of Black Sigatoka disease. One of the key elements in the network is its International Transit Center, established at the Katholeike Universiteit Leuven (KULeuven), in Belgium, to promote the free exchange of *Musa* breeding materials while minimising the risk of spreading diseases and pests. Under guidelines established by INIBAP and FAO, all banana and plantain samples exchanged worldwide or deposited in the INIBAP collection must be indexed for viruses at one of three internationally recognised centres of expertise (in France, South Africa or Australia).

When Gatsby was asked in 1993 to support IITA's *Musa* improvement programme, the work had reached a critical point. IITA's plant breeders in Nigeria had overcome the technical obstacles to breeding *Musa* species (see box) and had come up with several plantain varieties that were resistant to Black Sigatoka disease as well as having good agronomic characteristics and yielding an excellent crop of fruit. Efficient micro-propagation techniques had been developed as an integral part of the breeding programme and, as with other vegetatively propagated crops, tissue-cultured materials were routinely tested to ensure that they were free of virus diseases before shipping outside Nigeria. Yet reports had begun to come in that young *Musa* plants, grown from plantlets imported from IITA, were showing what appeared to be virus symptoms. The researchers were deeply concerned by this potentially damaging setback but were confident that it would be relatively straightforward to find a solution. 'Better virus diagnostic techniques, and the expertise to go with them, were needed urgently,' recalls Dr Jacqueline Hughes, IITA's senior virologist. The necessary expertise was available in the UK and could be brought to bear on the problems of the IITA *Musa* programme through a Gatsby-funded collaborative project.

Long road to better *Musa* varieties

Cultivated bananas and plantains are generally sterile, producing their fruit 'parthenocarpically', without fertilisation. This undoubtedly increases their palatability, but greatly complicates the process of improving these fruits through selective breeding. It also means that, for routine multiplication, plants must be propagated vegetatively—a relatively slow process.

Even those commercially or agriculturally useful varieties that show some fertility when crossed with fertile wild relatives still produce only very few seeds—perhaps one or two in a whole bunch; these seeds take as long as two years to grow into plants whose fruit and agronomic characteristics can be properly assessed; and most of these progeny will be inferior as crop plants to their cultivated parent. The techniques of biotechnology can help at several stages of the improvement process—from facilitating crosses, through saving the progeny of those crosses during their vulnerable early stages of development, to micro-propagation to speed up the process of multiplying promising materials. Recently, researchers have begun using genetic markers and genome mapping to characterise breeding materials and so to provide an early indication of whether the progeny of crosses have the desired characters. However, even with the help of biotechnology, the new varieties represent the product of a long and difficult selection process.

Each hanging bunch of bananas ends in a flower—but most cultivars produce no seeds.

IITA's new plantain varieties grow vigorously, even in the face of pressure from fungal and viral diseases.

The mystery deepens

Viruses comprise an extremely diverse range of organisms and simply identifying them, let alone treating or managing the diseases they cause, can present a challenge (see box). Fortunately, the combined efforts of IITA and JIC researchers soon resulted in diagnosis of the problem afflicting IITA's improved plantains as *Banana streak badnavirus* (BSV) (*Badnavirus: Caulimoviridae*). A period of intense research ensued, both in Africa and in the UK. Researchers at IITA needed to understand how the virus is transmitted among plants and under what circumstances its presence in a plant results in the expression of disease symptoms. At JIC, work focused on sequencing the virus and investigating its variability—a key issue affecting the reliability of diagnostic tests and the success of resistance breeding. Both groups of researchers were concerned to compare the results obtained using different kinds of diagnostic tests and to understand the differences.

The initial results, however, tended only to deepen the mystery. Plants that appeared virus-free in conventional tests, such as ELISA, did indeed begin to develop symptoms and to test positive for the virus after being exposed to various kinds of stress—including, most unfortunately, the artificial 'stress' of being passed through tissue culture. However, wider testing of plant material across Africa showed that BSV was already widespread in the region and was therefore unlikely to have spread via the breeders' improved materials, the dissemination of which had only just started. (Indeed, more extensive studies of the virus' variability have since shown that it could not have spread in this way, since locally occurring strains, for instance in Uganda, are quite different from those imported with the new crop varieties).

Fortunately, progress in molecular diagnostics was rapid and soon provided a clue to what was going on. 'We were already well placed to tackle this challenge, based on JIC's experience of working with related viruses,' recounts virologist Prof Roger Hull, who has guided the JIC input to this collaboration from its inception. Probes specific to the viral DNA were found to 'label'

Virus detective work

Identifying a virus accurately is difficult. The host plant may show distinctive patterns of discoloration or deformed growth, but symptoms often vary greatly from one plant species or variety to another, complicating identification on the basis of field observations. The 'classical' approach is to infect a standard test plant, such as *Nicotiana benthamiana*, which tends to show characteristic symptoms with a particular virus, but there are both logistical limitations and several possible sources of error in this approach. In some virus diseases, large quantities of viral particles build up in the affected cells of host plants, allowing their characteristic shapes to be recognised under an electron microscope. In others, however, the virus may be present in very small quantities or may not form distinct, identifiable particles. In these cases, the only reliable approach is chemical detection, either of the proteins produced in virus replication or of the genetic material of the virus itself.

Older chemical diagnostic methods, such as enzyme-linked immuno-sorbent assay (ELISA) tests, depend on identifying protein products using immune reactions, while the newer methods use molecular probes and focus directly on the nucleic acids of the virus. The accuracy of protein-based tests depends on the material originally used to generate an immune response. This may consist of whole virus extracts, used to develop polyclonal antisera, or of much more specific monoclonal antibodies, produced against parts of the proteins known as epitopes. These antibodies can be used to detect viruses with similar or identical proteins, but local variants may still not be picked up, with the result that some plants showing no reaction may in fact be infected.

Molecular techniques designed to identify viral nucleic acids are based on the polymerase chain reaction (PCR), which allows minute quantities of genetic material to be 'amplified' (duplicated over and over again) until sufficient DNA is produced for a sure identification. PCR-based tests can be several orders of magnitude more sensitive than protein-based tests. However, the variability of the virus genome needs to be sufficiently well understood in the first place to allow scientists to choose the right nucleic acid sequences on which to base a test. Although in principle viruses can be identified by sequencing the entire genome, this is prohibitively laborious and costly. The key to developing more efficient approaches is to identify the parts of the genome that vary and to develop tests that identify these variations.

A recent refinement is to combine protein- and nucleic acid-based approaches in so-called immuno-capture PCR (IC-PCR). In this approach, carefully chosen antibodies are coated onto the inside of a tube and used to 'capture' virus particles from a plant extract; this viral ribonucleic acid (RNA) is then transcribed to DNA and PCR is used to amplify it for proper diagnosis.

In the case of BSV, ELISA tests do not detect the form of the virus integrated within the *Musa* genome but may still be useful in confirming diagnosis once disease is evident. Increasingly, researchers are turning to more sophisticated tests, including IC-PCR.

sections of the host plant's chromosomes, even in plants that were disease-free and had tested negative for the virus in conventional tests. It took several more years of detailed research, and an extension of the Gatsby-funded project, to elucidate the details, but eventually a previously unknown kind of virus behaviour was revealed. 'It turned out that sections of the viral DNA could become inserted into the plant's chromosomes or "integrated" into the plant's genome, and in this situation there was no sign of disease or "episomal" virus, free in the cells of the plant,' explains Dr Glyn Harper of JIC, who has patiently pursued this detective work. Yet when the host plant was stressed in some way, the virus DNA could become excised from the plant genome and begin to replicate, causing disease. 'We still do not fully understand the evolutionary significance of this behaviour for virus and host plant,' continues Harper. The JIC researchers are also investigating the relationship between the opportunistic replication behaviour of the virus and the tremendous variability that has now come to light in field samples of BSV. However, the key lesson from this experience is already evident: sophisticated strategic research was needed to solve what at first seemed a straightforward plant quarantine problem.

Building on this strategic research, Gatsby has gone on to fund a project designed to place the benefits of improved diagnostics directly in the hands of national research organisations. These techniques are already being used to monitor the spread of BSV infection in test nurseries established as part of the germplasm dissemination projects (see below) and in due course will provide the basis for more extensive epidemiological and yield loss studies.

Initiating a chain reaction

Once diagnostic techniques were available that could reliably detect the various forms of the BSV virus, both in tissue culture and in complete plants, the dissemination of improved *Musa* varieties could begin in earnest. Virologists are hesitant to claim that plants are 'virus-free' and for BSV it is especially hard to be sure that the disease will not appear at a later stage; rather, the new tests meant that researchers were able to monitor the virus and this gave everyone concerned the confidence to proceed. The next step was to multiply enough of the new varieties to distribute to farmers. Once again, Gatsby was able to help, stepping in to support distribution projects in Ghana and Uganda.

Plantain plantlets in tissue culture begin the process of rapid multiplication.

Banana and plantain are conventionally propagated by cutting off the shoots or 'suckers' that form around the base of a mature plant and planting them separately to form a new stand of the crop. This approach can be used to extend a back-yard orchard, but it is a painfully slow way to spread new varieties, since only a few suckers are formed each year. This is especially the case if farmers follow their traditional practice of waiting for large suckers to form before separating them from the parent plant. The speed of the process can be greatly increased by using tissue culture as the first stage of multiplication, followed by 'false decapitation' in researcher-managed nurseries—a process that encourages plants to produce numerous small suckers. The material can then be handed on to farmers to multiply in the traditional way, but with some important modifications: the farmers should select only disease-free plants for multiplication; they can take smaller suckers than they are used to, to speed the process; and, most importantly, they must be careful to prevent the pest and disease problems that have devastated their traditional orchards from recurring. Ideally, they should disinfect their planting material by carefully paring all diseased and infested tissues from the suckers. They should then plant the suckers on fresh land or, where this is not available, radically improve orchard management, paying special attention to soil fertility.

Learning from the experience of earlier Gatsby-funded projects that distributed new cassava varieties (see Chapter 2), IITA worked with its national research partners to establish a linked series of banana nurseries, which would simultaneously multiply new materials, minimise virus incidence and allow farmers and researchers to compare the performance of the new cultivars with existing varieties. First, national scientists were to import tissue culture materials via the International Transit Centre and screen them for BSV, using ELISA and IC-PCR techniques (see box, p. 30), with back-stopping where necessary from IITA. Next the scientists would use tissue culture to multiply materials testing negative for the virus, which they would then harden off and establish in plantation nurseries. These nurseries would provide ideal conditions for further multiplication and the close monitoring of plants for BSV, initially on the basis of symptoms but backed up by molecular diagnostics as necessary. Lastly, once the necessary staff had been trained, the national team would use disease-free plants from these nurseries to establish secondary nurseries, from which planting materials could be disseminated directly to farmers. Farmers would be invited to participate in the evaluations from the plantation nursery onwards.

In Uganda, the importation of five IITA varieties (three of plantain, two of cooking banana) started the ball rolling in August 1996 and some 1400 plantlets were produced in the first six months, using IITA's local tissue culture laboratory. When the Gatsby project began in 1997, two FHIA varieties (from Honduras), two preferred local highland cooking bananas and two dessert bananas were added to the process, so that by August that year over 1500 plantlets had been transferred to screen houses at each of two multiplication sites. After removing any diseased plants and any plants not developing true to form, the researchers established field nurseries in November of that year and began field multiplication in earnest. During 1998 they were able to supply 400–500 suckers of each variety for planting on 48 farms at 13 locations spread over 12 administrative districts. Here the farmers were the principal evaluators and under farm conditions it was at last possible to see whether the improved materials really could outperform the existing land-races.

The results of the evaluations varied from one district to another, underlining the value of conducting these multi-location trials. None of the test materials remained entirely virus-free but some of the varieties are so tolerant of BSV that their vigour is not affected and only a specialist can tell that the plant is infected. Some of the imports were rapidly eliminated from the selection by farmers on the grounds of susceptibility to wilt disease or wind damage, but most were simply rejected as unpalatable. Plantains and cooking bananas in Nigeria are usually deep-fried in oil or roasted for immediate consumption: the first varieties produced by IITA's breeders were well suited for this use but not for making the *matoke* that Ugandans love so much. However, there is a growing market for roasting bananas in Uganda and one IITA plantain variety, PITA-14, is being enthusiastically adopted in Hoima District for this purpose while another, PITA-17, is being spread from farmer to farmer as a juice banana for brewing beer. Meanwhile a Honduran variety, FHIA-17, which is genetically similar to the local land-races, has been found to make good *matoke*. Released locally as Kabana 3, it is proving immensely popular and highly profitable (see Bananas mean business, p. 34). Because of the informal nature of the distribution system from secondary nurseries, no figures are available for adoption of the new hybrids. However, the researchers are trying to accept philosophically the theft of suckers from the nurseries—as a sign that these new products of their efforts really are acceptable to consumers!

In due course, the national breeding programme and IITA's ESARC researchers will doubtless come up with disease-resistant varieties that meet local agronomic and culinary preferences. In the meantime, the researchers are busy multiplying disease-free materials of the preferred local and exotic varieties identified so far. They have now produced over 20 000 tissue-cultured plants with which to establish the initial mother gardens and demonstration plots. These provide the basis for involving farmers in further evaluation and dissemination, and for raising the level of pest and disease management.

The multiplication chain has taken off rather more slowly in Ghana, perhaps because there were no IITA *Musa* specialists on hand to help respond to the inevitable technical hitches and because the national research institutions in Ghana have less experience of working with *Musa* than their counterparts in Uganda. During 2000 and 2001, the national team used tissue culture to multiply five IITA hybrids, one FHIA variety and four Ghanaian land-races at the University of Ghana, the Biotechnology and Nuclear Agricultural Research Institute (BNARI) and the Crops Research Institute (CRI), producing some 300 plantlets of each variety for field multiplication. In 2000, some 45 plants of each of the test varieties were planted at each of three test sites in different regions of Ghana for evaluation by farmers and researchers and to serve as mother nurseries for multiplication of the best varieties in subsequent years. National researchers have also begun to use the new diagnostic tools, both for disease surveys and to evaluate the new materials, while research and extension staff are becoming familiar with roguing for disease symptoms and with paring and hot-water treatment to disinfest planting material of weevils and nematodes. Action to schedule more regular exchange visits between researchers, establish better lines of communication and set and monitor targets is now helping to bring the project in Ghana up to speed.

Meanwhile, slightly different problems of palatability are coming to light. In Ghana, plantains are traditionally pounded with other starchy crops to make a thick mash called *fufu*, but when some of the new hybrids were processed in this way they went black or failed to produce the desired elastic consistency in the mash. Researchers are optimistic that it will be sufficient to suggest new recipes to win larger numbers of consumers to the new plantains, which are already attractive to farmers because of their high yields and disease resistance.

Sustaining the effort

The next challenge for the Ugandan programme is to ensure that the gains promised by the new varieties are consolidated and that the country's 'banana decline' is permanently reversed. With this objective, NARO's researchers have secured Gatsby support to help them work with farmers to develop the management strategies that will keep banana plantations healthy in the long term. Although the researchers who manage this extension effort have the elements of a solution in mind—higher-yielding varieties, pest and disease management, improving soil fertility—the focus of the project is explicitly on meeting the needs expressed by farmers. 'Our starting point was participatory,' says Dr Tushemereirwe, Leader of NARO's National Banana Research Programme. 'And it was also holistic, with a strong emphasis on the market. Instead of simply saying "Let's provide more productive varieties", we tried to find out what the farmers need to make banana growing a profitable, sustainable enterprise. This involves much more than just providing high-yielding cultivars.'

The NARO team chose as its target area the central region of Uganda. This used to produce most of the country's bananas, but over the past 10 years production has declined to such an extent that the fruit is now imported from elsewhere. The design of the project, focusing on a few sites but involving intensive co-operation between researchers, extensionists and farmers, was a deliberate reversal of past approaches. 'Our previous way of working was giving me a headache,' says Tushemereirwe. 'We had 21 sites; I had to visit them all often; the farmers regarded the plots as belonging to NARO and were not even weeding them unless told to do so. We had to find a better way. When we started the Gatsby-funded project, we selected only three benchmark sites, farmers elected their own representatives, and the project is controlled and implemented mainly by them.'

As in the previous dissemination project, the approach depends heavily on 'farmer trainers' such as Mukiibi, whose testimony begins this chapter. Initial training workshops involved government extension staff, NGO representatives and volunteers, who learned about new varieties and good management practices. These participants went on to organise farmer training workshops at parish level, at which over 1800 farmers recruited by their own communities have now received training. Of these, 395 have gone on to establish demonstration plots in their villages. These local arrangements also take over responsibility for the further multiplication of improved varieties, promoted through a 'two-for-one' distribution scheme (see box, overleaf). A total of 249 farmer-managed mother gardens have been established for secondary multiplication; about 600 new farmers are expected to have improved planting materials by the first rains of 2002; and researchers aim to distribute at least 6 million suckers by the end of the project in 2003.

Bananas mean business

Besides its emphasis on empowering farmers to help themselves and one another, the project's explicit orientation towards increasing farmers' profits represents a further step forward in the drive to maximise impact and create a self-sustaining development process. Mukiibi stresses the financial benefits from his new orchard: 'My improved bananas have been in the ground for five years and are still going strong. I can sell them for Ush 5000 (about UK£ 2.00) per bunch, and I can harvest 60 bunches every one-and-a-half months from half an acre. Compare that with the measly Ush 5600 I'm getting for my entire coffee harvest from twice that area!'

The extra income has made a huge difference to the family. The Mukiibis have 11 children, 8 of whom are now attending school regularly. But the most dramatic transformation is in the family's home: instead of a traditional round mud-walled thatched hut, they now have a smart brick-built house with a corrugated iron roof—a real symbol of status in the village and a significant

Two-for-one spreads the good news

Mr Haruna Mwezezi and his son are weeding their banana plot—something they seldom took the time to do in the past. What is more, they have recently begun to mulch their plants, improving their nutrition, and to control the growth of suckers, so that each plant grows only one strong sucker at a time.

Why all this extra care? Like hundreds of other small-scale banana farmers in Central Uganda, Mwezezi has been provided with improved planting material and with the training needed to get the best out of it. The material was given to him by Mukiibi, his local 'farmer trainer' and a participant in an effective combined multiplication and training system devised by the NARO team on the basis of earlier experiences with cassava. In each parish, 'farmer trainers' are selected using certain criteria, such as being trustworthy and hard working, being prepared to manage their banana orchards actively, and having land that has not had banana growing on it for at least two years. Mwezezi was given 50 suckers of improved local or exotic varieties and taught how to manage them. In return, he undertook to give out his first 100 new suckers to other farmers in the area, who would then also give two away for every one they receive. And he also undertook to pass on his knowledge of how the plants should be managed.

A key element in the recovery programme is to prevent the re-introduction of pests and diseases to new or rehabilitated plantations. Farmers undergoing training in multiplication are also being taught to select disease-free plants and to pare off any pest-damaged roots and stem tissue from the base of the suckers. 'In our initial survey we noticed that farmers were routinely planting poor-quality suckers,' says NARO's Tushemereirwe. 'So we believe this training is absolutely vital to the project's success. Once the farmers understand why it is so necessary to use clean planting material, they will spread the information through their groups and networks.'

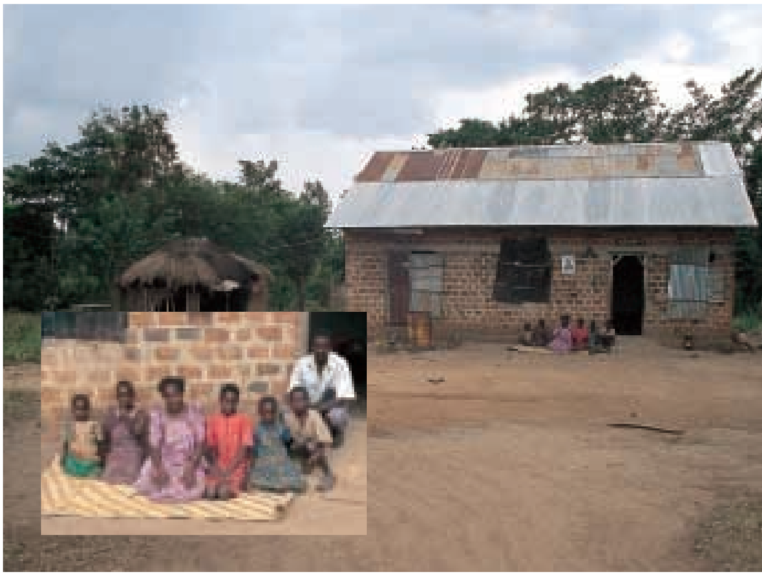
In this way, the project has developed an effective system for spreading both the new materials and the knowledge needed to grow them successfully. A huge impact has been achieved in a short time, with little supervision by NARO researchers.

Haruna Mwezezi with one of the first 100 suckers he is committed to giving to other farmers enrolled in the project.

Farmers meet regularly to discuss the best ways to improve the management of their bananas. Farmer groups are important vehicles for the exchange of information and knowledge, and give the farmers stronger negotiating power with traders and markets.

contribution to the family's quality of life. 'It took only two seasons to earn enough money for this roof, and now we can eat *matoke* three and sometimes even four times a week. I am very happy.'

Is there a risk that the project will be too successful and simply saturate the market for bananas? Farmers at the first benchmark sites in Luwero District have already turned their deficits into surpluses, with the result that the area is no longer importing the majority of its bananas from elsewhere. For the time being, at least, there would appear to be plenty of scope for continuing growth in production. With NARO support, the Luwero farmers have begun supplying more distant markets. They have established a successful roadside trading site from which their produce leaves for the huge urban market of greater Kampala. A Kenyan trader is also buying two truckloads a week to take over the border into neighbouring western Kenya.



Mukiibi shows off his new house, which he built himself with materials bought from his banana profits.

Together, the projects on bananas in Uganda show what can be achieved when a donor or group of donors invests concertedly in the successive stages of the innovation process, from strategic research, through applied research and technology development, to adaptive R&D and support for dissemination at local level. As so often occurs in agricultural development, particularly in Africa, several constraints had to be addressed—some technical, some social or economic—before an impact on the lives of producers and consumers could be achieved. This can be a slow business, requiring successive phases of research along different avenues over a period of decades. In this case impact came relatively quickly, largely because Gatsby had the commitment, in addition to the flexibility, to tackle each constraint as it became apparent. The general lesson to be drawn is that, whether this is done by a single donor or by a consortium, impact is only achieved when *all* the roadblocks to progress have been dismantled.

Projects in brief

Banana streak virus diagnostics

Partners: JIC and IITA.

Timescale: 1994–1996; extended 1997–1999.

Aim: To develop techniques for BSV indexing of *Musa* germplasm.

Rationale: BSV is widespread in *Musa* germplasm, but the relationship between virus infection and disease expression remains to be fully clarified. IITA should only disseminate materials that have been properly indexed for this virus. The lack of adequate indexing techniques jeopardises the dissemination of IITA's high-yielding, stress-resistant *Musa* planting materials.

Progress:

- Sensitive, PCR-based diagnostic techniques for BSV were developed and successfully used to underpin the dissemination of new *Musa* cultivars.
- In the process of carrying out the basic research needed to understand the virus, it was discovered that BSV constitutes a novel form of virus that can be integrated into the host plant genome, breaking out in response to stress to replicate and cause disease.
- Surveys using the new diagnostic techniques have shown that numerous and diverse BSV strains or species are prevalent in Uganda and that their presence is not associated with the recent importation of germplasm.

Inter-country transfer of BSV diagnostics

Partners: IITA and various national research programmes.

Timescale: 1997–2000.

Aim: To transfer reliable techniques for BSV detection to national programme scientists.

Rationale: Various forms of BSV have been found to occur almost ubiquitously in *Musa* germplasm, though not all are associated with disease or risk of disease. Researchers in Africa need access to reliable diagnostic tests that will enable them to: monitor the incidence of BSV in improved germplasm imported in tissue culture form; maintain disease-free planting stocks as the basis for multiplication of improved germplasm; conduct national surveys to understand the incidence of BSV; and conduct trials to quantify the significance of BSV-associated losses under local conditions in land-races and imported *Musa* germplasm.

Progress:
- Modified ELISA and IC-PCR diagnostics have been successfully used by researchers in Ghana and Uganda to monitor (and where necessary manage) BSV incidence in extensive germplasm multiplication nurseries and to evaluate BSV impact on local and imported *Musa* germplasm in multi-location trials.

Disseminating improved IITA *Musa* varieties to farmers in Uganda

Partners: IITA and NARO.

Timescale: 1997–1999.

Aim: To make available to farmers healthy, disease-resistant, improved varieties of banana and plantain.

Rationale: Black Sigatoka and BSV are among the most widespread and destructive diseases of banana and plantain. Vigorous, high-yielding, disease-resistant or -tolerant varieties, suitable for use by small-scale farmers, have now been developed by both FHIA and IITA, but most African countries lack institutions equipped to test and disseminate such materials adequately.

Progress:
- Five improved varieties from IITA and two from FHIA, with Black Sigatoka resistance and BSV tolerance, have been imported, indexed for BSV and multiplied in tissue culture, along with two Ugandan land-races and two dessert varieties.
- New diagnostic tests have been developed and used to exclude BSV from multiplication stock and staff have been trained to manage rapid disease-free multiplication.
- All test materials have been planted out and evaluated by farmers and researchers at 48 farms in 12 districts.
- Secondary multiplication sites have been established for farmer-to-farmer dissemination and farmers have been trained in multiplying pest- and disease-free stock.

Disseminating improved IITA *Musa* varieties to farmers in Ghana

Partners: IITA, CRI, BNARI and University of Ghana.

Timescale: 2001–2003.

Aim: To make available to farmers healthy, disease-resistant, improved varieties of banana and plantain.

Rationale: Black Sigatoka and BSV are among the most widespread and destructive diseases of banana and plantain. Vigorous, high-yielding, disease-resistant or -tolerant varieties, suitable for use by small-scale farmers, have now been developed by both FHIA and IITA, but most African countries lack institutions equipped to test and disseminate such materials adequately.

Progress:
- Five IITA hybrids have been imported and multiplied in tissue culture, along with one FHIA variety and four Ghanaian land-races.
- Three mother nurseries have been established in different regions and staff have been trained in the rapid multiplication of healthy stock.
- Molecular diagnostics have been successfully used to monitor the health status of nurseries and to assess the incidence of BSV in local plantations.

Improving banana crop management systems in Uganda

Partners: NARO, with IITA, ICIPE, Makerere University, Buganda Kingdom, Agricultural Extension, Volunteer Efforts for Development Concerns, World Vision, and farmers' groups.

Timescale: 2001–2003.

Aim: To revive banana production in central Uganda through the transfer of improved crop management techniques to farmers.

Rationale: Banana is an important food security crop in this part of Uganda. Productivity has fallen drastically over the past 20 years due to pests and diseases, soil fertility decline, socio-economic constraints and low genetic diversity. It is possible to break out of the complex of pests and diseases by replanting with clean materials on land that has either been planted to other crops or is under fallow. The dissemination of improved cultivars generated mainly by tissue culture is an integral part of this strategy.

Progress:

- Farmers' banana technology needs have been identified.
- Approximately 40 000 tissue-cultured plants and suckers have been distributed to farmers.
- Some 249 on-farm mother gardens have been established for secondary multiplication.
- Over 1800 farmers have been trained in improved planting and management techniques.

5. Growing tall and strong:
private-sector innovation supports sustainable forestry

Africa's fuelwood crisis

Images of women walking along the road carrying large bundles of firewood on their heads are evocative of everyday life in rural Africa—and a favourite holiday snap in many a tourist's photo-album. But how many of those who wind down the car window in order to 'take' this passing slice of rural life realise, as they accelerate away from it, that behind the picture lies a tale of human drudgery and environmental destruction that perpetuate the cycle of poverty and hunger holding millions of Africans in its grip?

In Africa as elsewhere in the developing world, forests are a vital resource. They provide people with several of life's basic necessities—food, fodder, fuel and timber. And they also perform valuable environmental services, maintaining the soil and water balance, harbouring biodiversity and helping to stabilise the world's climate by absorbing carbon dioxide. Africa has even less primary forest left than Asia and Latin America—and what remains continues to be cleared at an alarming rate as the region's rapidly growing human population demands more and more land for agriculture and more and more timber for building homes and making furniture, tools and other goods.

This Ugandan woman spends many hours collecting firewood—time that would be more productively spent on growing and preparing food.

Fuelwood is the main source of domestic energy for cooking throughout most of sub-Saharan Africa. In the highlands it is also a source of warmth, as temperatures fall at night or during the rainy season. And it is needed to power many of Africa's small-scale processing industries.

As fuelwood becomes scarcer, women and children have to spend more time and energy collecting it—time they could be allocating to more productive tasks that would earn the family an income. When fuelwood runs out altogether, families must resort to alternatives such as crop residues and animal dung, which cause health problems with their toxic smoke and mean that less organic matter is returned to the soil. The result is that crop productivity suffers and incomes and subsistence levels fall still further as the whole livelihood system undergoes a further downward twist in the spiral of decline. Things are no better in the cities, where many poor people can no longer afford to buy fuelwood but have no access to alternatives such as gas or electricity either. In both town and country, people are cooking less often and eating more raw food, which is less nutritious and more likely to spread diseases. High-protein foods, such as beans, may be out of the question, as they take too long to cook.

In Kenya, the demand for fuelwood far exceeds supply and, unless urgent action is taken, the country will soon face a fuelwood crisis. At present, around 3 million trees are planted every year, but an annual planting rate of between 15 and 40 million is needed just to keep pace with current demand. Even if enough seedlings are planted now, it will be 10 years or so before they reach harvest-able size. Public awareness campaigns have made rural people more aware of the importance of trees and the need to use fuelwood more efficiently, but tree planting efforts are often inefficient. There is little screening of germplasm to select the most productive provenances, traditional seed propagation is slow and germination rates are low, the quality of seedlings is poor with a high incidence of disease, and most growers perceive trees to need little care after planting. Where commercial production from seedlings has been tried, the results have been largely disappointing due to low rates of survival, slow growth and the production of uneven stands that are difficult to manage.

'There is an urgent need to speed up tree production and improve its quality in Kenya,' says Dr Florence Wambugu, former Director of the Africa programme of the International Service for the Acquisition of Agri-biotech Applications (ISAAA). 'Biotechnology can help us do both those things.' ISAAA already has valuable experience in harnessing the potential of biotechnology to help small-scale farmers improve the productivity of key food and cash crops, especially banana. Acting as an 'honest broker', the Service brings together partners from the public and private sectors, who work together to facilitate the transfer, multiplication and dissemination of improved planting materials. 'There was no reason why the benefits of tissue culture—its ability to produce large quantities of disease-free plantlets in a short time—could not be applied to tree production. We just need to treat trees like any other crop,' adds Wambugu.

A roadside tree nursery near Nairobi, Kenya. Entrepreneurs collect seeds from local forests to grow and sell. The system meets a need, but the seedlings are of poor quality and from unknown varieties, and they often carry diseases.

Careful planning is central to ISAAA's strategy—and has contributed to its impressive track-record in attracting resources and generating an impact. To Wambugu and her colleagues, that means starting with a clearly identified need, choosing partners carefully and developing a detailed strategy not just for introducing technology but also, crucially, for marketing the end product. All this happens long before funding is sought or the first seeds are sown. 'It is this planning stage that lays the foundations for success,' stresses Wambugu.

Accordingly, when Gatsby was approached to fund the ISAAA-brokered Tree Biotechnology Project, detailed planning—including that of an exit strategy for donors—had already been done. The project aims to provide fast-growing, disease-tolerant tree seedlings to smallholders, using high-quality planting material produced through tissue culture and vegetative propagation techniques. Propagation by tissue culture has the potential to produce a large number of genetically identical, disease-free plantlets in a short time. These are then planted in nurseries where they form 'clonal hedges' from which cuttings are taken and placed in a rooting medium, before being transplanted for growing out. This technology ensures that farmers planting cuttings can achieve a uniform stand of trees that maintain the desired characteristics.

This tree project represents a further step in the evolution of Gatsby's approach. Like its predecessors, the project aims to improve the productivity of a key commodity needed by the poorest sectors of the community: small-scale farmers and poor urban consumers. However, it pursues this aim by involving the private sector as a full partner in both the acquisition and the dissemination of new technology. In addition, the project has focused initially on commercial buyers of its product, in order to achieve self-funding status quickly. It thus has the potential to create a substantial impact for a relatively small donor investment. 'The participation of private-sector companies and entrepreneurs has enabled us to access relevant new technology and knowledge without having to generate it ourselves; it has made the whole project more accountable to budgetary and time constraints; and, most importantly, it has led to the quicker delivery of a marketable product that is much in demand among consumers,' says Wambugu.

Another new feature of this project is its emphasis on building the infrastructure, as well as the human capacity, needed to ensure long-term sustainability. While previous Gatsby-funded projects had successfully trained many of their participants, the Foundation had hitherto been reluctant to invest in physical facilities. 'We had to work hard to convince Gatsby that it was right,' Wambugu recalls. 'But the need, and the potential benefits, were clear, so in the end we won them over.'

A productive partnership

At the heart of the project is a partnership between two public-sector organisations—Kenya's Forestry Department, represented by the Forest Health Management Centre (FHMC), and the Kenya Forestry Research Institute (KEFRI)—and Mondi Forests, which is the tree research division of Mondi Ltd, a private South African paper and timber products manufacturing company that is part of the Anglo-American Group. 'Finding the right partners is the key to sustaining the project's activities and ensuring long-term impact,' says Mr Sam Wakhusama, the current Director of ISAAA's AfriCenter. 'At first glance, getting a government department and a large private company to work together might seem problematic, but in fact they complement each other well and the arrangement should prove mutually beneficial.'

The participation of Mondi was based on its previous track record: the company had already successfully developed and adapted tissue culture techniques for the large-scale production of tree plantlets and had valuable experience in working with various species of *Eucalyptus* that were of particular relevance to the Kenyan situation. These species, some of which are fast growing and hence prolific providers of fuelwood, formed the project's priority focus. Mondi Forests were looking to expand their operations in Africa, but needed local knowledge and assistance in order to access the East African market. The company also needed information on how different species and hybrids of *Eucalyptus* would perform in different environments. However, besides pursuing conventional commercial objectives Mondi also aimed to play a role in improving livelihoods and alleviating poverty in Africa. In this the company is typical of the more compassionate private sector that has emerged in recent years, particularly in South Africa, as this country seeks to recover from decades of socially divisive policies. ISAAA is one of several institutions that have been able to harness the new South Africa as a source of expertise to benefit the rest of the region.

The Forestry Department and KEFRI were the obvious national partners for the project, since they share the R&D mandate to tackle Kenya's fuelwood crisis. Both institutions brought to the project their extensive network of national contacts and detailed background knowledge of Kenya's forestry sector. KEFRI had some previous experience in the use of tissue culture for clonal tree production but needed further technical training and facilities, as well as access to improved tree provenances and hybrids.

In addition to designing and brokering the project, one of ISAAA's early tasks was to clarify the legal and financial implications of acquiring technology from the private sector. The use of the clones developed by Mondi was, in principle, limited by the company's intellectual property rights, so the question was how to assure adequate returns to the company for the materials it was contributing.

The basis of the private–public partnership that has evolved to disseminate the improved tree technology in Kenya is that the capital costs of project development, especially the costs of developing a central tree nursery, have been met mainly by Gatsby and, to a limited extent, by the

Government of Kenya. If this enterprise had been established as a purely commercial venture by a private company, these start-up costs would have been met by the company and its investing partners, and would have been repaid over time by the returns accruing from the sale of seedlings and clonal cuttings. In return for the opportunity to enter the Kenyan market without having to front these costs, Mondi Forests agreed to supply its technical expertise and a set of clones for the initial trials programme free of charge. However, royalties will be payable on the germplasm selected for subsequent production and, to cover this, a license agreement with a trading company is needed. This agreement will require the company to pay royalties on the value of its audited sales. The company, which is now being established, will pay a proportion of its income to a not-for-profit entity (specifically, the Kenya Gatsby Trust), which will use this money to pay the royalties. The discussions surrounding these arrangements in Kenya have also been useful to the Ugandan Gatsby Trust, which is developing a similar model as the tree project's activities expand to include that country.

Returning to Kenya, there are now several additional collaborating organisations. The most important of these is Genetic Technologies Ltd (GTL), a Nairobi-based private-sector biotechnology company. GTL has expanded its existing tissue culture operations to include tree propagation and is thus set to play a vital part in mass-producing plantlets for distribution to nurseries. Another vital component of the distribution network are the nurseries themselves—at present there is one central nursery, near Nairobi, but regional 'grow-out' nurseries will be established at strategic sites around the country where fuelwood is scarce. As the project continues, its network of contacts will be expanded still further, laying the foundations for scaling up both in Kenya and in neighbouring countries. All the project's principal partners are represented on its local steering committee, which maintains the project's direction and vision.

Getting started

Despite the thorough planning, the first three years of the project were problematic. Acquiring land for trial plots and installing services (electricity and borehole water) for the central clonal nursery were difficult and slow processes. The original project manager lacked the time and commitment needed to get the project off the ground. However, since Mr Benson Kanyi took over in 2000, progress has been rapid. The central clonal nursery has been established on a 5-hectare site in Karura forest, just outside Nairobi, and is now producing half a million seedlings a year.

The project is concentrating initially on evaluating and accelerating the production of eucalypts—the natural species *Eucalyptus grandis*, *E. saligna* and *E. tereticornis,* as well as the 'GC' hybrid (*E. grandis* × *E. camaldulensis*) imported from Mondi (see box). The hybrid is particularly interesting since it is both highly productive and tolerant to drought, making it suitable for the drier areas of Kenya where fuelwood scarcity is most acute. However, it is intended that the project will diversify to include other species, notably *Grevillea robusta* and *Acacia melanoxylon*. *G. robusta*, silk oak, is the most popular multi-purpose agroforestry tree in Kenya, being widely used by small-scale farmers to provide fuelwood, fencing and building poles in addition to shade and windbreaks. *A. melanoxylon*, the Australian blackwood, is a fast-growing alternative to the endangered native ebony, which has been overexploited to supply the expanding wood-carving industry.

Eight of the *Eucalyptus* clones donated by Mondi Forests have performed well in initial trials and are considered suitable for large-scale production in Kenya. They are now being tested in further field trials located in different agroecological zones. The project can already recommend different species for these zones (see table). The GC hybrid is proving particularly useful in the semi-arid zone, where early trials with farmers have revealed its

Clonal eucalypt hedges at the central nursery, Karura, Kenya.

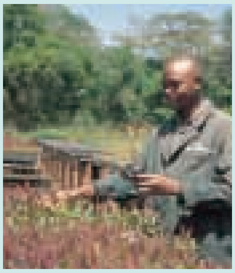
Eucalypts with a difference

Eucalypts were introduced into East Africa from Australia around 100 years ago. In Africa they have an extended flowering season, with the result that considerable new genetic diversity has arisen through cross-pollination, in addition to natural adaptation to different climatic conditions. Eucalypts are popular because they grow fast and the wood is used by industry as well as by farmers, mainly for firewood and charcoal but also for fence poles and stakes. The materials introduced from South Africa were selected and bred by Mondi for rapid growth, efficient conversion into energy and other useful characteristics.

Tissue culture of eucalypts results in materials that are even faster growing, free of most diseases and resistant to common fungal and insect attack. A further advantage is that the trees show considerable uniformity of growth, making them ideal for commercial forestry. They grow to a size suitable for firewood and stakes after just one year, or fencing and telephone poles after four years and can be harvested for electricity poles and sawn timber after just six or seven years.

Seedling of the drought-tolerant hybrid E. grandis × E. camaldulensis, *which is proving particularly suitable for the drier parts of Kenya.*

Mr Minjire Muraya, manager of the project's central nursery, is proud of the nursery's 12 500 mother plants, arranged in clonal hedges, from which he and his colleagues propagate cuttings for sale to clients. 'We can harvest every two weeks, and these plants will maintain production for up to 10 years,' he says. The cuttings are carefully rooted in vermiculite, then kept under controlled conditions for a month before being hardened off outside; they are ready for sale around three months after harvesting.



Muraya checks the seedlings for quality before they are sold.

Nursery staff are experimenting with different ways of improving the survival of cuttings and obtaining better germination rates from seed. 'We receive all our training and backstopping from Mondi,' says Muraya, 'but we are constantly adapting and experimenting to find out what are the most cost-effective methods for our local conditions.'

The nursery also provides jobs, employing 16 full-time staff and taking on a further 180 casual workers at busy times. If, as is hoped, other nurseries are soon launched, the project's contribution to employment will grow still further

Eucalypt cuttings growing in controlled conditions in the rooting section of Karura tree nursery.

Ecological adaptations of different *Eucalyptus* species in Kenya

Species	Elevation (m)	Annual rainfall (mm)
E. grandis	1200–2000	> 900
E. camaldulensis	0–1200	450–900
E. tereticornis	0–1200	450–900
E. urophylla	0–1600	> 900
GC hybrid[1]	0–1200	600–1400

[1] *E. grandis* × *E. camaldulensis*

potential as an income earner in areas where there are few reliable alternatives (see box). GTL have multiplied the Mondi materials through tissue culture and supplied them to the project's central nursery, where they now form impressive clonal hedges. These 'mother plants' provide the cuttings that are sold on to farmers and other clients.

In addition to cuttings, the central nursery is also producing improved planting material from seed, using high-quality seed from Mondi. The team are testing different methods of seed production to determine which are the most cost-effective. Seedlings will provide an alternative and less expensive form of planting material for resource-poor farmers who do not need the uniformity of growth ensured when buying a batch of clonal plants derived from tissue-cultured plantlets or cuttings.

Training has been an important part of the start-up phase. The nursery manager was trained at Mondi Forests in South Africa, while senior Mondi staff have paid several training and advisory visits to Kenya to help plan and set up the nursery and later to train the nursery staff in propagation techniques. GTL's newly acquired expertise in micro-propagation of tree species also has its origins in Mondi.

Is the on-farm production of eucalypts sensible from an environmental point of view? Eucalypts have sometimes been criticised as trees that lower the water table and deplete soil nutrients. Kanyi is confident that any potential problems can be avoided. 'There is a lot of genetic diversity within the species and we can breed, select and adapt what we have, so as to minimise any environmental problems,' he argues. Information dissemination will be an important part of the distribution strategy and the team will advise people not to plant their trees too close to a river or well. Despite its reputation for being a heavy drinker, *Eucalyptus*, like other tree species, can also help to conserve soil moisture by creating shade, reducing surface runoff and increasing water percolation into the soil. It can also be strategically placed to dry out farm areas susceptible to flooding or waterlogging. The depletion of soil nutrients can be mitigated if nutrient-rich biomass (especially foliage and bark) is left on site when wood is removed. Adverse ecological effects in general

An income-earner for the dry areas

Mr Maxwell Kinyanjui has a small plot of land near Kitengela, in Kenya's Kajiado District, where rainfall is usually less than 500 millimetres per year and is very unreliable. He has been experimenting for several years with different species of acacia and eucalyptus, and has recently tried planting *E. grandis* × *E. camaldulensis* hybrids, which he obtained from the project nursery. 'These trees are amazing. They can survive on as little as 1 litre of water per week for four weeks after planting, then will grow and flourish without watering at all,' he exclaims. 'My neighbours all want to know where I got them!' Trees are a valuable cash crop in low-rainfall areas such as this, where the only alternative is livestock. 'This could be a whole new industry for Kenya and represents a huge business opportunity for people like us,' says Kinyanjui.

Mr David Muraya is another Kajiado farmer who has been won over by the superior eucalypts. He decided to plant the hybrids on his farm when his bean crop, already suffering from drought, was eaten by a herd of zebras that broke through the fence. Muraya has already planted 5000 seedlings and plans to plant a further 3000 during the next rainy season. His first trees, planted in May 2001, now stand over 4 metres high. 'These trees really grow fast,' he says. 'This plantation is my investment for the future and is going to provide my pension. It is an excellent crop to make use of my dry, infertile piece of land.'

Maxwell Kinyanjui (left) and David Muraya with a fuel-efficient kiln for making charcoal.

Muraya's drought-tolerant hybrid eucalypts after nine months' growth.

can be minimised if eucalypts are planted in a patchwork with arable crops, other tree species and natural vegetation.

The way out

The project's vision is to create a self-sustaining production and marketing system, without losing sight of the principal objective of benefiting resource-poor smallholders. Current predictions are that the break-even point will be reached at an annual sales figure of about 3 million plants. Initially it was expected that at least half the sales would have to be to agri-business companies in the commercial sector. In late 2001, however, it became clear that the larger co-operatives (grouping small-scale farmers) were keen to buy on behalf of their members. In the first year of marketing, more than half a million seedlings and cuttings were bought by the Kiambu Dairy and Pyrethrum Co-operative Farmers Union, which groups several thousand farmers in the country's Central Province. The project will continue to give this market high priority, alongside sales to more remote community groups, which usually buy relatively small quantities, and to commercial buyers, amongst whom there is a high level of interest.

To drive the sales effort, a marketing company will be established by the Kenya Gatsby Trust, which is already active in supporting local enterprise. Besides concentrating on sales, the marketing company will ensure that profits are re-invested in creating an efficient and effective distribution network. The extension part of the operation is expected to be self-funding and will focus on generating awareness and further demand among small-scale farmers.

Scaling up

The value of piloting a project on a small scale to test methodologies and spot constraints before attempting to scale up is well established. In this case, several potential constraints need to be addressed as the project is scaled up within Kenya and extended to other countries. The first is that of price. Despite the anticipated economies of scale, which should lead to reduced prices, the cost of buying improved seedlings may still be prohibitive for resource-poor farmers. It remains to be seen

Quality seed of improved eucalypts being sown at the Karura nursery.

how farmers will respond as the performance of the trees becomes more widely known.

The second constraint could be a supply bottleneck, especially once marketing activities raise awareness of the advantages conferred by the new planting materials. The supply of basic tissue-cultured materials has been assured by bringing in GTL who, in contrast to public-sector laboratories, have the capacity to multiply and deliver in bulk. But a further problem may lie in the development of the regional and local nurseries needed to disseminate the technology more widely. Again, the project may turn to the private sector to address this need, seeking entrepreneurs who will be willing to tap into the experience and knowledge of the central nursery at Karura in order to launch one of their own.

In Uganda, the project is at a very early stage, but it is already envisaged that private investment will play an even larger role than in Kenya. Gatsby has funded the establishment of a small clonal nursery for demonstration and training purposes (see box, overleaf). It is hoped that this will encourage private investors to establish their own nurseries, which will again be supplied with superior material through tissue culture for further multiplication using the clonal hedge technology. The project staff in Uganda are already benefiting from the experience gained during the early phases in Kenya.

Legal and contractual issues pose another potential constraint on successful scaling up in new countries, as each national programme will have to

Trial plot to evaluate performance of Mondi Eucalyptus *varieties at Kiambu, Kenya.*

negotiate its own agreement with Mondi. However, experience gained during the early phases of the project is likely to make these negotiations more straightforward. And in Mondi the project has found a partner that recognises the need for mutual advantage in any partnership.

Lastly, it will be important to keep a watchful eye out for pest and disease problems, particularly in the case of large commercial plantations in which a single species is established. The project is already playing its part in saving biodiversity by collecting germplasm and initiating tissue culture propagation protocols for native tree species, including some that are threatened with extinction.

The way ahead

The Tree Biotechnology Project provides an example of development that appears sustainable both economically and ecologically. The social and economic benefits of extensive tree planting include meeting the urgent need for fuelwood and timber, freeing up women's labour for more profitable tasks than fetching firewood, creating a source of income for resource-poor farmers, making fuelwood more affordable for the urban poor, and creating job opportunities in the rest of the economy. Among the environmental benefits are the prevention of further deforestation, with its accompanying risks of erosion and loss of biodiversity, and the storage of carbon dioxide, which will help to stabilise the global climate.

The project's unique feature is the collaboration it has fostered between the public and private sectors. Two initially unlikely bedfellows, Mondi Forests and the Kenya Forestry Department,

Averting a fuelwood crisis in Uganda

Fuelwood is becoming critically scarce in Uganda. Population growth is putting intense pressure on natural forest in a country where political instability and conflict have resulted in very few trees being planted during the past 30 years. Managed stocks of conifer wood are due to run out in less than 10 years. Privatisation of the electricity industry in late 2001 sent prices soaring by 150%, putting even more pressure on fuelwood as a source of energy.

There is great potential for tissue-cultured eucalypts here, with growth rates of up to 6 metres per year expected in the wetter areas of the country. The plan is to start with ready-made technology from Mondi, including *E. saligna, E. grandis* and *E. grandis* × *E. camaldulensis* hybrids, then to expand production to include the locally popular *Grevillea robusta*, an *Acacia* hybrid with potential for timber and pulp production, and *Melicia excelsa* (iroko), a native hardwood that has been exploited to the point of extinction.

The site of the Uganda Tree Biotechnology Project at Kifu in February 2002.

The Tree Biotechnology Project in Uganda is again facilitated by ISAAA and brings the country's Forestry Resources Research Institute (FORRI) into partnership with Mondi Forests. 'The project is very timely; the political will for this activity is now there; and Ugandan farmers are just beginning to wake up to the potential of tree production, with many NGOs becoming involved,' says Dr Epila-Otara, Principal Research Officer at FORRI. 'We are well placed to replicate Kenya's success and to create rapid and widespread impact.'

have demonstrated that they can work together to mutual advantage. More importantly, the emphasis on achieving a self-sustaining dissemination system early in the project's life should provide Gatsby, as donor, with an exit strategy.

It is too early yet to say whether this new approach will be wholly successful. However, if the project does succeed it could well provide a model for the design of future projects—with other commodities, other biotechnology applications and other countries. The project aims to be producing 3 million seedlings per year by the end of 2002. Assuming a reasonably successful establishment rate, these could create up to 25 000 or so additional hectares of trees per year, making a significant impact on the preservation of native forest in addition to providing badly needed fuelwood. But there could be wider benefits still. In addition to its impact on poverty alleviation and the environment, the project could influence a shift in government and donor priorities towards greater private-sector involvement, leading to a more sustainable system of technology development and dissemination.

Projects in brief

Tree biotechnology

Partners: KEFRI, FHMC, Mondi Forests and ISAAA (Kenya); FORRI, Mondi Forests and ISAAA (Uganda).

Timescale: Kenya: 1997–2003; Uganda: 2000–2004.

Aim: To improve the living standards of the rural and urban poor by enhancing forestry production through the integration of improved tissue culture forestry biotechnologies into traditional tree propagation systems.

Rationale: Demand for forest products (especially fuelwood) is increasing, placing indigenous forests under considerable stress. There is a need for increased quantity and quality of planting materials for economically important tree species. Tissue culture provides large numbers of fast-growing, disease-free plantlets within a short time.

Progress:
- A central clonal nursery has been established in Kenya with 12 500 mother plants.
- This nursery now produces half a million rooted cuttings per annum plus half a million seedlings from seed.
- Clonal trials have been established in seven different agro-ecological zones of Kenya.
- Strong partnerships have been established with the private sector.
- A national capacity in tissue culture has been developed.
- A nursery site in Uganda has been completed and the first clones have been received for planting.

6. Advanced research on Africa's neglected crops:

transforming the prospects for cowpea, yams and plantain

Ancient crops, modern methods

In the harsh climate of West Africa's dry savannas, cowpea, along with drought-tolerant cereals such as pearl millet and sorghum, formed a key element in a stable, intensive production system that fed the densely populated city-states of this region over several centuries. West Africa still produces about 1 million tonnes of cowpea each year—over 90% of the world's total—providing grain and green vegetables for human consumption, as well as fodder to help livestock through the dry season and nitrogen-rich crop residues to restore soil fertility. Meanwhile, further south, along the margins of the forest, yams are so important that they have achieved a quasi-religious significance, symbolising prosperity and fertility as well as providing a major staple food. In the early 1980s, Nigeria alone produced some 18 million tonnes of yam tubers annually and Côte d'Ivoire a further 2 million tonnes. Of this crop too, West Africa accounts for some 90% of the world's recorded production.

When IITA was established in 1967, these two traditional staple crops were among the priority candidates for improvement. Both had been neglected by commercial plant breeders and there appeared to be tremendous scope for increasing their productivity. Cowpeas (*Vigna unguiculata*) had received some attention in the southern United States (where they are known as black-eye peas), but the varieties produced were unsuitable for West African conditions; white yams (*Dioscorea rotundata*), which are native to West Africa, and water yams (*Dioscorea alata*), originating from Southeast Asia but now more important in West Africa, seemed scarcely to have been considered by plant breeders anywhere.

Over the next 25 years, the donor community invested substantial resources, mainly in conventional crop breeding, to improve these crops for the benefit of sub-Saharan Africa. Considerable progress was made but, as each pest, disease or physiological constraint was alleviated, another came to the fore, blocking progress towards higher productivity. In the early 1990s IITA and its partners turned to Gatsby for help in bringing the latest tools of biotechnology to bear on this problem—or, more accurately, series of problems. The Foundation was well placed to support this work because another element in its programme, larger and longer-established than its involvement in African agriculture, was its funding of basic and applied molecular biology research in the UK, via the Sainsbury Laboratory and various projects at JIC. Projects on yams and cowpea in West Africa provided an opportunity to bring Gatsby's investment in basic plant science in the industrialised North to bear on solving practical development problems in the South. However, the challenges involved were novel and formidable, and the prospects for success difficult to assess.

Before 1994, Gatsby and its partners had taken mature or near-mature technologies, which had already demonstrated their potential for farm-level impact, and facilitated their dissemination to farmers. Now the Foundation was to help researchers generate some of the new supporting technologies that were needed to catalyse the flow of improved varieties to farmers' fields: gene maps of both yams and cowpea, primarily to support the conventional breeding effort through the identification of genetic markers; and molecular diagnostics for yam viruses, again to support conventional breeding but also to remove obstacles to the dissemination of improved yam germplasm. Beyond that, the scientists hoped to achieve major gains in the productivity of cowpea by 'transforming' the crop: bringing in pest-resistance genes from wild relatives and conferring resistance to key viruses by bringing in genes from the viruses themselves.

This venture into the field of biotechnology took Gatsby's Africa programme beyond the common-sense world of agricultural extension and drew it into a complex multi-stage process of scientific innovation (see figure). The various technical, organisational and political obstacles encountered along the way taxed the Foundation's recognised flexibility and commitment as a donor. In this chapter we examine some of the lessons learned in the course of this foray to the cutting edge of agricultural research.

Yams resist attempts to improve them

'Yams were a challenge to us from the beginning,' says Dr Robert Asiedu, IITA's yam breeder. 'We had plenty of germplasm accessions and we knew that virus diseases were among the key constraints, but both the germplasm and the viruses were poorly characterised.' Many yams—and the symptoms of the viruses they carry—are superficially similar, but vary according to growing conditions. Add to that the practical constraints that most yams do not flower readily and that, when they do flower, their crosses tend to be sterile, and it is evident that the breeder's 'challenge' was in practice something of a nightmare (see box).

Yet yam breeders did make considerable progress by largely conventional means, developing resistance to anthracnose disease, caused by the fungus *Colletotrichum gloeosporioides*, and to nematodes. The new varieties of water yam that incorporated these traits yielded about twice as much as existing local cultivars while preserving acceptable tuber shape and taste. Improved white yams with similar characteristics yielded 30% more than the best local check varieties. Tissue culture

Polyploids with attitude

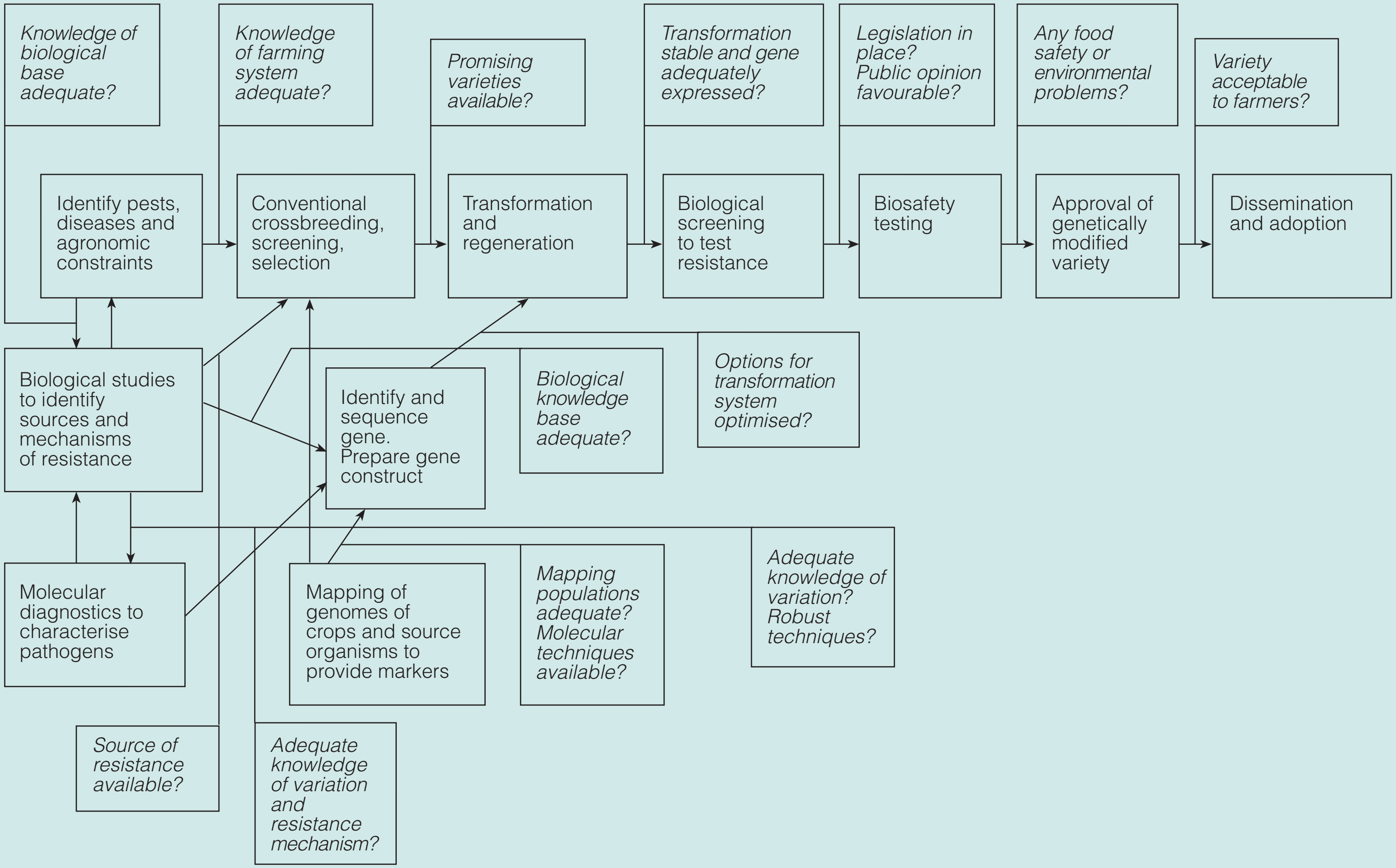
Farmers find it so convenient and reliable to propagate yams vegetatively, from tuber setts that produce genetically identical copies of the parent plant, that over generations they have given up using the seeds of yams entirely—and the crop itself has largely dispensed with sexual reproduction, becoming dependent on its human cultivators to ensure its multiplication. When plant breeders began trying to increase the diversity of yams by conventional crossbreeding, they faced several difficulties associated with this evolution. Yams produce male and female flowers on separate plants and long-cultivated clones now consist entirely of either male or female plants. Some clones scarcely ever flower or, if they do, the pollen or ovules may be sterile. Even if the breeder manages to persuade two chosen varieties to flower simultaneously, they may not produce fertile seed. Then it transpires that even viable seed may not germinate readily and, as the breeder tries to hurry on to the next generation, the tubers may remain obstinately dormant for several months.

Over years of effort, yam breeders discovered a series of 'tricks' that enabled them to induce flowering in many clones, break dormancy and otherwise induce the plants to co-operate with the breeding programme. However, it needed biotechnology to lay the foundations for more rapid progress by helping the scientists understand the genetics of the crop and the variability among clones.

One of the challenges in crop breeding is to characterise the genetic variation within a crop species, to understand how its varieties are related to one another, and then to explore the relationships between the species and any wild relatives with which it might be crossed to introduce useful characteristics. Traditionally, breeders relied on visual assessment of plant characters and trial and error to see which plants could successfully and usefully be crossed. With plants that are as hard to cross as yams, it becomes especially important to gain a better idea of which clones are most likely to be compatible, both in the general sense of being closely related and specifically in terms of whether they have compatible chromosome numbers. Yet yam clones are so similar to one another in appearance that they give few clues as to their underlying genetic relationships. Molecular markers offer breeders a chance to delve beneath appearances to assess relatedness at the molecular level and explore the genetic basis of relevant traits.

Like many vegetatively propagated crops, yams turned out to be 'polyploids'—organisms with multiple sets of chromosomes. Polyploidy is often associated with extra vigour and does not necessarily exclude sexual reproduction. With even numbers of chromosome sets, that can pair up tidily with their 'homologues' during fusion of pollen and ovule, viable seed can result, just as it can in diploid plants having two sets of chromosomes. However, the presence of multiple sets of chromosomes increases the possibility of errors occurring during pollen and ovule formation, leaving some plants with extra genes and others with an incomplete genome. The result may be a plant with useful characteristics, but it will no longer be fertile and will henceforth have to be propagated vegetatively. With the help of genetic markers, breeders can start to investigate how many copies of particular genes a yam clone possesses, whether the copies are identical or varied, and how they are grouped on the chromosomes. Yams turn out to have a basic (haploid) chromosome number of ten, but cultivated varieties have at least four sets (tetraploid) and may have six or eight. Small wonder that they were hard to cross!

Steps towards innovation in biotechnology. Developing a variety transformed for pest or disease resistance is a multi-stage process, involving conventional biological studies and institutional change in addition to the use of techniques from the biotechnology toolbox. All steps must be completed successfully if a genetically modified crop variety is to be deployed and impact seen at farm level.



techniques—part of the basic toolkit of biotechnology—came in useful for speeding up the process of multiplication and dissemination. Yams can be even slower to multiply by conventional means than other vegetatively propagated crops such as cassava and banana: traditionally farmers put aside fully one-quarter of their harvest to provide 'setts'—pieces of tuber to start the new crop. The scientists not only developed 'mini-setts' that farmers and extension services could use for rapid multiplication, they also discovered how to stimulate yam plants growing in artificial culture medium to produce numerous micro-tubers.

The micro-tubers were largely free of contaminants and, being even more vigorous than conventional tissue-cultured plantlets, were ideal for shipping to other nascent root crop programmes around Africa, as raw material to launch their own breeding and multiplication programmes. The remaining obstacle standing in the way of progress was to work out how to deal with viruses—how to identify them properly, how to ensure that tissue-cultured material was free of them and how to breed for resistance. The researchers came to Gatsby for help in developing better virus diagnostics, together with a molecular map of the yam genome to underpin the breeding effort through the identification of markers.

Tiny yam plants, grown on sterile nutrient medium, are prepared for shipment by a technician at IITA's Biotechnology Laboratory. Such 'plantlets' provide a safe means of transferring germplasm to other countries—once viruses have been excluded.

Yam viruses identified

With Gatsby support, IITA and other partners undertook three yam virus diagnostic projects, designed to investigate different aspects of the yam virus problem. 'At the time these projects were launched,' recalls Dr Jacqueline Hughes, IITA's senior virologist, 'our knowledge of yam viruses was very sketchy.' *Yam mosaic potyvirus* (YMV) (*Potyvirus: Potyviridae*), accompanied by other potyviruses, appeared to be prevalent in white and yellow Guinea yams (*D. rotundata* and *D. cayenensis*) and in various other West African species of *Dioscorea*, wild and cultivated. These aphid-borne viruses caused various discoloration and deformation symptoms, depending on the host and the environment, and were believed to be responsible for significant yield losses. Asian water yam, on the other hand, mainly suffered from the mealybug-transmitted *Dioscorea alata* bacilliform virus, now known as *Dioscorea alata badnavirus* (DaBV). Hughes continues: 'These two major viruses and a range of other, less well characterised ones, were enough to paralyse germplasm movement into West Africa and to prevent IITA from distributing improved varieties to collaborators anywhere outside Nigeria.' A range of diagnostic techniques, based on serology, electron microscopy and symptoms in test plants, were being used to try to understand the virus complex. However, these were not providing reliable enough 'indexing' to permit the safe movement of germplasm and researchers were unsure whether they were combating a handful of viruses or many.

Although the molecular techniques to be used in this project represented only minor modifications of existing protocols, the work on yams proved to be problematic. For instance, at first it proved impossible to purify viral nucleic acids directly from yams, so viruses had to be passed first into *Nicotiana* plants. Similarly, 'blotting' techniques, routinely used to detect viruses in extracts from other plants, could not be used on yams because of the glutinous nature of their sap. Eventually, however, extraction, purification and detection systems were developed and could be put to work. Diagnostic techniques for DaBV, developed in collaboration with the UK's Horticultural Research Institute (HRI) and JIC, allowed 31 new land-races of water yam to be brought to Nigeria from Japan, Nepal, Taiwan and the Pacific region to enrich the breeding programme for Africa; and two new genotypes developed by IITA could be certified for distribution. The potyviruses of Guinea yams were progressively sorted out and a range of serological and PCR-based diagnostic techniques were developed at IITA and NRI through collaborative projects led by Drs Lawrence Kenyon and Sue Seal of NRI. Part of the coat protein gene of YMV has been found to be especially suitable for characterising these viruses.

'We're proud of the progress we've made on yam virus diagnostics. But the problem is not yet fully solved,' cautions Hughes. 'Obtaining a reliable diagnosis in the field can still be difficult and the tests are still too expensive for routine use, especially for national researchers working on a tight budget.' Trials in Ghana and Nigeria, conducted by NRI's Drs Ed Canning and Rick Mumford, have shown that, as expected, the PCR-based techniques are more sensitive than the serological tests, but the latter are less expensive and more practical for use in West African laboratories. Work in this area therefore continues.

In the meantime, the tests developed for YMV and related potyviruses have enabled Asiedu and his team at IITA to get on with the practical business of breeding better yams. Using the new diagnostics, combined with conventional biological studies and breeding experiments, doctoral student Mr Babajide Odu has studied the various aphids vectoring yam mosaic, identified sources of resistance to the disease in land-races of *D. rotundata* and *D. alata*, as well as in wild relatives, and established the pattern of inheritance of this resistance in *D. rotundata*. The synthesis of the new knowledge of viruses, generated by the Gatsby-funded projects, can now be built into the mainstream breeding effort.

A gene map to guide future improvements

Mapping techniques are becoming routine for many crops, but mapping the yam genome proved to be something of a step into the unknown: yams are not closely related to other crops and it was unclear what techniques would work. Indeed, at the outset of this project, there was even some controversy as to which major branch of flowering plants, monocotyledons or dicotyledons, yams belong to. By the end of the project it was evident that yams are 'monocots', but so different from other crops in this branch (banana and wheat are more closely related to one another than yams are to any other crop) that, in retrospect at least, it was hardly surprising that standard tests and reagents failed to work!

The first priority for IITA molecular biologist Dr Jacob Mignouna was to gain a better understanding of the evolutionary relationships between the various *Dioscorea* species of West African origin, as a basis for improving the chances of achieving successful outcrosses between cultivated yams and their wild relatives. For this purpose research focused initially not on mapping yam chromosomes but on comparing the DNA contained in chloroplasts and ribosomes—cell organelles which evolve in parallel with the nuclear genome of the organism and can give a good indication of genetic similarities and differences between species.

Another important aim was to characterise the existing yam germplasm collection, which at the start of this project already included some 3000 accessions. A germplasm collection provides the raw material of a breeding programme, but it is only useful to the extent that breeders know what genetic traits it contains and which of these traits are accessible for crossbreeding. Yam varieties are extremely hard to describe and separate on the basis of conventional morphological characters (leaf shape, tuber colour, etc) because these characters tend to vary in response to growing conditions. Moreover, farmers' own varieties, on which the initial collections were often based, sometimes comprise a mixture of genotypes which just happen to be broadly similar in appearance (or some other character of interest to the farmer, such as tuber texture), but are not necessarily closely related genetically. Such puzzles can only be resolved by molecular marker techniques. Mignouna and his colleagues used two such techniques, namely random amplified polymorphic DNA (RAPD) and amplified fragment length polymorphism (AFLP), to develop procedures for 'genetic fingerprinting', which allows varieties to be distinguished from one another accurately and relatively rapidly. The results of these studies will continue to bear fruit long after the end of the Gatsby-funded projects—

both at IITA and at other institutions, such as the Ghana Plant Genetics Resources Centre, which have adopted the characterisation approaches developed by the project partners.

Progress on the formal mapping effort, for both the *D. rotundata* and the *D. alata* genomes, has been slow. In both yam species, land-race varieties were crossed with improved lines from the breeding programme in order to develop a mapping population, but because of the difficulties of characterisation referred to above there is some lingering doubt as to whether these parents were the right ones for the job. Progress has also been delayed by the technical hitches that seem to have beset all stages of the molecular research on yams, resulting in too few progeny being available in the mapping population and too few markers being identified to establish an adequate map. Undaunted, the team are now looking for different kinds of marker which will help to provide a more complete map. And in the meantime much useful information, of practical value to the breeding programme, has been gathered about the inheritance of individual traits, especially resistance to YMV, anthracnose and yam nematodes.

Progress and setbacks in cowpea improvement

In the 1970s, a multidisciplinary team at IITA set to work to 're-design' cowpea—from the nitrogen-fixing nodules on its roots to the pods and peas themselves—just as their counterparts in Asia and North America had re-built rice and wheat as high-performance crops. Two, sometimes three, full-time legume breeders, supported by a physiologist, pathologist, entomologists and a small army of support staff, collected well over 10 000 lines of cowpea germplasm, carried out thousands of crosses and conducted hundreds of field trials at numerous locations across Africa, in collaboration with a growing band of legume breeders in national programmes. By the mid-1980s the breeders felt reasonably satisfied with their efforts to combat diseases, having developed several high-yielding varieties with good resistance to 11 major viral and fungal pathogens. However, these varieties were still highly susceptible to several destructive insect pests and farmers did not readily adopt the package of monocropping and insecticide application needed to grow them successfully (see box).

The trouble with cowpeas

Cowpea came from Africa and, like many crops growing in their area of origin, it is afflicted by a succession of pests and diseases that have evolved to exploit each of its parts: *Ootheca* beetles, *Empoasca* leafhoppers and various aphids attack the growing seedlings, spreading virus diseases; thrips attack the flower buds, causing them to fall before they have the chance to form seeds; and so on, through successive growth stages, until bruchid beetles attack the grain at harvest and in store. IITA's legume breeding team made tremendous progress in the 1970s and 1980s, producing several varieties with high yield potential and 'multiple resistance' to the major diseases. They also identified useful sources of resistance to two insect pests—thrips and bruchids. However, they could find no convincing answer to two other extremely destructive kinds of pest: the pod-borer *Maruca vitrata*—a moth whose larvae tunnel in the developing pods—and a guild of pod-sucking bugs, such as *Clavigralla tomentosicollis* and *Riptortus dentipes*, which pierce and suck the sap from the developing pods, leaving them deformed and empty of grain. Both kinds of pest have host plants other than cowpea and are strong fliers that can arrive in huge numbers, devastating the crop at the vulnerable pod- and seed-forming stage. The pod-bugs usually arrive from nearby woody legumes, while *Maruca* migrates each season from the humid coastal zone to the inland savannas. In both cases, mass invasion by these pests goes some way to explaining why plant breeders have found it so difficult to select for resistance.

By the early 1980s IITA had developed early-maturing cowpeas that, grown as a monocrop, produced a much higher yield than traditional varieties—but only if protected from *Maruca* and pod-bugs by three applications of pesticide. Adopted as a complete 'package', the new cowpea-with-insecticide technology gave very favourable rates of return and was adopted by almost one-third of farmers in parts of northern Nigeria. Outside these small areas, however, the package was not widely adopted, either because few resource-poor farmers could afford even the relatively low amounts of pesticide and the ULV sprayers required, or because the intermittent failure of pesticide supplies brought the risk of crop failure even to those who could afford these inputs. In any case, a catastrophic devaluation of the Nigerian currency in the mid-1980s tipped the balance firmly against the new technology. Imported inputs were now too expensive, giving an overall negative return on the package.

The breeders went back to the drawing board to develop new plant types, better suited to intercropping and to the production of animal feed as well as grain. They made steady progress and soon their new offerings reliably outyielded farmers' cultivars, even without the use of pesticide. The improved plants contributed both to soil fertility, from the increased production of nitrogen-rich biomass, and to incomes, through the sale of fodder. Yet by the early 1990s, when IITA turned to Gatsby for help, essentially the same road-block—susceptibility to insects—still stood firmly in the way of further progress, while a further threat to yields, the parasitic weed *Striga gesnerioides,* had begun building up in farmers' fields. Even with the new generation of improved varieties, the gain in yield over existing cultivars was fairly marginal unless pesticide was applied, so adoption by farmers was still limited. By this time pesticide supplies in Nigeria were, if anything, even less reliable than before. To achieve a significant increase in yields, the breeders were therefore more than ever dependent on genetic resistance to the key insect pests—a trait that could not be found in the cultivated crop but which might well be present in wild relatives. To access the trait from these genetically more distant sources, the scientists decided to try the technology of genetic transformation.

A dual strategy

In applying the techniques of advanced research to improve cowpea, IITA's team pursued a dual strategy: to underpin the breeding effort, the researchers set about developing a map of the cowpea genome, which would be a source of molecular markers for key traits of interest (see box); at the same time, they continued and broadened the search for insect resistance, in preparation not just for conventional breeding but also for genetic transformation. In particular, other *Vigna* species appeared to have the resistance to key insect pests, especially *Maruca*, that cultivated cowpea lacked and so were potential sources of transgenes. A third option, considered as a back-up plan, was to introduce known genes from *Bacillus thuringiensis* (Bt), which had already been used to transform other major crops for insect resistance. Gatsby provided support through two projects, while complementary aspects of research were funded by other donors.

By the time Gatsby began funding work on the cowpea map, the IITA team had already made a good start. The first approach, widely employed in mapping other crops, involved the use of restriction enzymes to cut the plant's DNA into fragments and

The parasitic weed Striga gesnerioides *causes severe losses to cowpea under intensive production.*

Markers save time and resources

Genetic markers are most immediately useful to breeders when they are so closely linked to a trait of interest that the breeder can follow the inheritance of the marker in place of the trait itself. This is especially the case when the trait is something that appears late in the life of the plant (such as a grain characteristic), is complicated (such as drought tolerance) or is otherwise cumbersome to screen for directly. 'Take the example of *Striga* resistance,' explains Dr Christian Fatokun, a cowpea breeder who has turned enthusiastically to molecular methods to push forward IITA's sometimes frustrating quest for stress-resistant cowpea. 'We know that *Striga* populations are variable and that some of our cowpea materials resist one form or geographical race but not others. I make a cross between two lines to try to combine both forms of resistance in one variety. The progeny of my cross will have a range of resistance characteristics: some will have no resistance, some will be resistant to one or other *Striga*, like their parents; and some will have the combined resistance that we need. Previously I would have had to breed up pure lines from each group and send them to test nurseries where we know that the different strains of *Striga* occur before I could tell which lines had the desired characteristics. This would have taken several full growing seasons—and there would still have been the possibility of "escapes" and other screening errors. Now, using molecular markers, I can take a piece of tissue from each of the small seedlings from the initial cross and I will know within a matter of hours which plants carry which resistance genes.' IITA's cowpea breeders are continuing to look for markers that will help them to select for resistance to bruchids (bean weevil), two major viruses and various environmental stresses.

to look for variation in the size and nature of those fragments—so-called restriction fragment length polymorphisms (RFLPs). Researchers had placed some 90 RFLP markers on the map, including markers for resistance to Cowpea chlorotic mottle virus (*Bromovirus: Bromoviridae*) and quantitative trait loci (QTLs) for seed weight and pod length. Markers are especially helpful when breeding for traits which are controlled not by the presence or absence of a single gene but are built up 'quantitatively' by several genes, or in other words QTLs, that must be kept together as selection proceeds.

Good gene maps are often built up using several different kinds of marker. Under the collaborative arrangements established for the Gatsby project, the IITA team was able to speed up the mapping work by bringing in probes already developed by its partners for other crops, such as common bean and soybean, as well as new techniques for identifying markers. RAPD markers depend on the use of PCR to amplify specific DNA sequences and are more sensitive than RFLPs for distinguishing between closely related species or varieties. The Gatsby-brokered partnership between IITA and JIC gave IITA access not only to RAPDs but also to AFLPs, which currently constitute the main tool being used in the cowpea mapping project. 'Our priority now is to convert the DNA markers into sequence-characterised amplified regions (SCARs) that we can use directly for screening purposes,' says IITA's cowpea breeder and molecular biologist, Dr Christian Fatokun.

Successful mapping depends critically on the populations chosen for the inheritance studies on which the map is based. The parent plants of the mapping population must differ for the genes of interest. For instance, if *Striga* resistance is the main interest, one parent must be resistant, the other susceptible—and if they differ in other ways as well, the inheritance of those traits too can be investigated. One plausible general strategy is to cross two plants that are as unrelated as possible, within the range that will produce fully fertile progeny. These progeny are then crossed among themselves and inheritance is studied as characteristics segregate in the F_2 generation. For the yam mapping effort, uncertainty over both the relatedness of clones and their level of fertility in crossing was the source of recurring problems. In the case of cowpea, an initial cross was made between an improved variety from the IITA breeding programme belonging to the species *V. unguiculata unguiculata* and a wild relative regarded as a distinct form or subspecies, *V. unguiculata dekindtiana* var. *pubescens*. Ninety-four recombinant inbred lines were established from the progeny and these continue to be used as the mapping population.

The use of mapping techniques to search for *Maruca* resistance genes, as a prelude to transformation, did not go so smoothly. Since cowpea shows no *Maruca* resistance, there was no point in seeking *V. unguiculata* mapping populations that differed for this trait. *Vigna vexillata*, a wild member of the same genus as cowpea, was thought to be the most promising source of a resistance gene, since laboratory tests had shown this species to be highly resistant to the pod borer. But, after a further intensive search of the germplasm, it turned out that *V. vexillata* had the converse of cowpea's problem: there were no susceptible populations of this plant. Fortunately, yet another search revealed what was needed: *Vigna oblongifolia*, another wild relative, appeared to have both highly resistant and somewhat susceptible populations, allowing the search to continue.

In the meantime, the stakes for the transformation effort had been raised by a new and severe virus problem that came to light when IITA's high-yielding cowpea varieties were tested in Southern Africa. The varieties had proved highly susceptible to local variants of two viruses, Cowpea aphid-borne mosaic virus (CABMV) and Bean common mosaic virus (BCMV)-blackeye cowpea strain, both *Potyvirus: Potyviridae*. Rather than undertaking the painstaking search for resistance to these newly problematic viruses by conventional screening, the project partners decided to pursue a potential short-cut opened up by recent work on the chemical mechanisms by which genes operate and viruses replicate. If a segment of DNA corresponding to one or more virus genes can be introduced into the plant's genome, that DNA can block the synthesis of the corresponding gene in the genome of the invading virus, 'silencing' its expression and preventing the virus from replicating. The use of inserted virus coat protein genes had been shown at JIC to work well in protecting other crops against aphid-transmitted potyviruses, so there seemed to be no reason why this should not also work for cowpea. The pressing need now was for an effective transformation system for the crop.

Can cowpea be transformed?

Although legumes in general were regarded as 'recalcitrant to transformation', there was no reason to suppose, at the outset of this project, that transforming cowpea would present insurmountable obstacles. JIC already had experience and technologies in-house that had been successfully used for similar work on other legumes, including common bean, soybean, groundnut and peas.

In 1994, when the project began, cowpea could not be routinely regenerated into viable plants from undifferentiated callus tissue, so efforts focused on introducing genes into various kinds of embryo or meristem tissue. At JIC, the first year's work involved using a 'gene gun' for microprojectile bombardment, a process in which tiny gold particles carrying the genetic material (in this case a reporter gene and activator) are fired into the embryo tissue. This approach had worked for common bean, soybean and groundnut, but despite trying various options—and achieving what looked like appropriate penetration of the target tissue—the team were unable to repeat their success in cowpea. The scientists refocused their attention on the use of *Agrobacterium tumefaciens*, a soil organism that has proved a successful vehicle for introducing genes into other crops, including peas and various forage legumes. Work proceeded in parallel at JIC and IITA, using various cowpea tissues and antibiotic treatments, the latter serving to exclude *Agrobacterium* from the plants regenerated from the transformed tissue.

Molecular biologists engaged in this kind of research usually work with 'reporter' genes until they have developed a successful transformation system. In principle, a reporter gene produces an easily detectable product once it has become incorporated into the genome of the target crop and successfully activated (for instance, the *gus* reporter gene triggers the synthesis of b-glucoronidase, which produces a blue stain in the transformed plant tissue). In practice, it can be tantalisingly difficult to know whether the gene really has been incorporated and, in the case of the cowpea project, there were several occasions on which transformation seemed to have been achieved, only for hopes to be dashed.

Thousands of plantlets were treated with each of the two main types of transformation protocol. But of the treated plant preparations, fewer than half could be regenerated into viable shoots and plants; and of these only a handful expressed the reporter gene, indicating that they had been transformed, at least transiently. In 1997 the investment of effort seemed to have borne fruit when the IITA team announced that they had achieved transformation, with the expression of both the *gus* reporter gene and a Bt gene in whole transformed cowpea plants. Meanwhile, research proceeded apace at JIC to investigate the variation in the potyviruses for which resistance was sought, to choose the nucleic acid sequences most likely to confer wide resistance and to assemble these sequences into constructs suitable for insertion into cowpea.

It is difficult to know exactly how or when the optimism that characterised the early stages of the project began to fade. However, at some point it became clear that IITA's announcement had been premature: the introduced genes could not be inherited or were no longer expressed. One possibility was that the antibiotic treatments had not been sufficiently rigorous and it was genes carried by contaminating *Agrobacterium* whose expression was being observed. Whatever the explanation, the introduced genes had not been permanently incorporated into the cowpea genome. Work continued for a while at both JIC and IITA, whose scientists tried to follow up the most promising leads and continued to look at the gene introduction strategy, now taking into account the fact that only a low success rate could be expected. A model plant, *Nicotiana benthamiana*, which could be routinely transformed, was used instead of the tricky cowpea, but even in this plant the inheritance of virus resistance and markers did not turn out as expected.

Eventually the effort was put on the back burner, not because all avenues had been exhausted or the strategy was fundamentally unsound but because of a sober recognition that a major new investment would be needed to give the endeavour even a reasonable chance of success. Using the most promising (*Agrobacterium*-based) transformation protocol currently available, only one in a thousand plantlets exposed were showing even transitory evidence of new gene expression. To follow up adequately, against such long odds, would require more time, space and materials than any of the partners was prepared to invest.

With the benefit of hindsight, it is tempting to suggest that the odds on success were probably not so favourable as the optimistic project proposals had suggested. And perhaps better communication between the partners or more careful co-ordination of their efforts would have avoided mistakes and reduced duplication of effort. However, the bottom line is that any research in this field is currently speculative and any donor wanting to invest in it must carefully weigh the potential benefits against the possibility of failure. Certainly, as the case of Bt-transformed cotton in China illustrates, the rewards can be great. Farmers using this technology have reported higher net returns to their enterprises coupled with significant environmental and human health gains.[1] And in the case of IITA's parallel attempt to transform *Musa* species for virus resistance, the researchers appear to be on the threshold of a major breakthrough (see box). In sum, the prospects for successful transformation and for a positive impact on the lives of producers and consumers still seem good enough to justify investing in the next stage in the deployment of genetically modified crops, which is to prepare for them politically and organisationally.

Preparing the way

As genetically modified crops are developed, it is important to make the necessary institutional arrangements for biosafety testing and to ensure that national decision-makers are sufficiently familiar with the key issues surrounding deployment to take informed decisions on this subject. Several parties have addressed this task in sub-Saharan Africa, but Gatsby has played a key role in advancing the agenda in West and Central Africa through a project initiated in parallel with the IITA-JIC biotechnology projects.

The advanced research techniques employed in the Gatsby-funded yam, cowpea and *Musa* projects were, in principle, little more than an extension of conventional plant breeding strategies (which include 'wide crosses' to bring useful genes into crops from their wild relatives). However, the work took place against a background of changing public perceptions of genetic modification: the new generation of transformed crops, including maize, soybean and cotton, attracted relatively little interest when these crops were first grown on a large scale, initially in the United States and then in China, Brazil and a few other countries; but during the 1990s public unease began to grow, especially in Europe, and the fall-out from this concern was felt in crop breeding efforts in Africa and other developing regions.

Like most other institutions involved in developing the new biotechnologies, Gatsby and IITA took a non-doctrinaire stance, stressing the need to balance the potential risks and benefits and to weigh these against the costs, as is done when developing any new technology. There was also work to do to put in place an adequate regulatory framework. This would ensure that transgenic versions of African crops could be tested for their environmental and health impacts, in line with the 'best practice' already pursued in the industrialised countries. This work, which in virtually all African countries involves developing new institutions and procedures, takes time and must be tackled early in the research process if it is not to become an obstacle to progress later on.

In Nigeria, IITA has worked with successive governments, both within and outside the aegis of the Gatsby-funded project, to develop national biosafety guidelines, and there are signs that other countries in the region are gaining the confidence to tread the same path. A regional approach came a step nearer in February 2002 with a workshop convened at IITA to bring together scientists, politicians and the press to look at biosafety issues; although focused on the needs of Nigeria, which provided the majority of participants, the meeting also brought in representatives from Benin, Burkina

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1 For a description of these benefits, see Pray et al (2000). Impact of Bt cotton in China. Paper presented at the Fourth International Conference of the International Consortium on Agricultural Biotechnology Research (ICABR) on the Economics of Agricultural Biotechnology, 24–28 August, Ravello, Italy. Similar results have been reported in other countries, including South Africa.

Musa successfully transformed at IITA

A major byproduct of the basic studies on BSV (see Chapter 4, p. 30) is that it may soon be possible to transform banana and plantain for resistance to this virus and possibly to other stresses too. The novel approach to 'gene silencing', discussed above in relation to cowpea viruses, is expected to work equally well for the badnavirus of *Musa*—and will in this case obviate the need for a long and difficult screening process. Already Dr Glyn Harper and his colleagues at JIC have sequenced a number of BSV genes, identifying sequences that are highly 'conserved' (i.e. similar to one another) across a wide range of strains of BSV and which therefore would be candidates for conferring durable resistance.

Meanwhile, IITA's Dr Leena Tripathi and her colleagues are confident that they have achieved stable transformation of plantain. The path to this achievement was almost as tortuous as that for cowpea, similarly involving different transformation systems and premature claims of success. At one point work at IITA was suspended, as project collaborators at KULeuven announced the development of a system involving the suspension of *Musa* cells in a liquid culture medium, followed by the regeneration of complete plants. However, IITA was unable to obtain the free use of this technology in its own facilities and so Tripathi's team were obliged to focus once more on developing their own transformation system. They used *Agrobacterium*-mediated transformation of shoots derived from excised apical meristems. Transformed plantlets propagated through tissue culture have been shown to express the *gus* reporter gene and can be grown on in the screen house, under an appropriate biosafety regime, to form fully viable plants. The integration of the reporter gene has been confirmed by PCR. There is no reason in principle why this system should not be equally successful in introducing the sequences prepared by JIC to confer BSV resistance and, in due course, resistance to other stresses such as fungal diseases and drought. Thus the team are tantalisingly within reach of having superior, genetically modified *Musa* plants, ready for testing in the real world.

Leena Tripathi and Patricia Ogunsanya check transformed Musa *plantlets in tissue culture (left). As plants develop, they are hardened off and then maintained in a screen house (right), pending biosafety testing.*

Faso, Cameroon, Ghana and Niger. Among sub-Saharan African countries, only South Africa has biosafety regulations on the statute books and transgenic crops in farmers' fields. However, it seems likely that, as gene technology continues to offer both commercial opportunities and significant contributions to food security and environmental protection, other countries will not be far behind.

Who should do the research?

When IITA established its biotechnology unit in 1987, researchers were concerned that the substantial investment needed to use the tools of biotechnology successfully might distort the Institute's priorities and divert resources away from tried-and-tested methods. The Institute decided that it would not undertake work that could more effectively be undertaken in better-resourced 'advanced laboratories' in industrialised countries. Rather, it would focus on activities that supported its conventional crop improvement efforts and its principal task of supplying improved crop genotypes and technologies to national programmes in Africa. This principle continued to guide the discussion of 'comparative advantage' that determined which components of the cowpea and yam biotechnology projects should be undertaken by IITA and which should be carried out by JIC or other partners in the industrialised world.

Dr Andy Maule of JIC, one of the leaders of the collaborative research effort with IITA, is confident of the role that 'advanced research institutes' such as his own can play: 'It costs hundreds of thousands of pounds to set up a well-equipped biotechnology lab. Most developing countries do not have the necessary resources to use the full range of technologies available and do not have enough trained personnel to cope with their existing research priorities, let alone the new ones implied by the more complex forms of biotechnology. We can readily take the techniques developed in our work on basic plant science and on temperate crops, and help our counterparts in developing countries to apply them to problems in tropical crops. This way everyone wins.'

It is perhaps more difficult to define the appropriate role of institutions such as IITA, based in the developing world and with a focus on tackling practical development problems, yet possessing some of the facilities and resources of their partners in the North. The leader of IITA's Crop Improvement Division, Dr Rodomiro Ortiz, explains it like this: 'Our responsibility is to keep abreast of developments in the field of biotechnology and to ensure that our partners and clients in developing countries are not denied the benefits of promising new technologies.' Some would argue that institutions such as IITA, with their clear focus on development objectives and on tropical crops, are better placed than basic research institutes in the industrialised world to facilitate the adoption of the most useful biotechnologies by developing countries. As Dr Ivan Ingelbrecht, head of IITA's Biotechnology Laboratory points out, whatever arrangements are used to support developing country research, they should not condemn African scientists to using secondhand or second-rate technologies. Echoing Maule's point about the prohibitive cost of setting up a comprehensive biotechnology facility in most developing countries, Ingelbrecht suggests that the answer lies in being strongly objective-oriented, helping national institutions to select and invest only in the technologies most useful to them. 'For instance, a PCR unit these days costs only about US$ 5000,' he points out. 'Combined with the right training and supplies of appropriate probes and reagents, many of which are available from our own work or through our collaborations with laboratories overseas, an investment of this size is enough to place the best diagnostic techniques available in the hands of those who need them most: developing country researchers who are in the front line of the battle for food security.' Under the Institute's new strategic plan for biotechnology, IITA will place increasing emphasis on building the capacity of national partner organisations in molecular diagnostics and other fields carefully targeted to tackle specific challenges.

In practice there are many reasons why such technologies and benefits will not, by themselves, flow to the researchers and farmers of developing countries. In contrast to the technologies previously used in crop improvement, many of the cutting edge biotechnologies are being developed in the private sector (as commercial assets), rather than in universities and publicly funded research institutes (as international public goods). Market forces alone are unlikely to bring these technologies to developing countries because commercial firms see little economic return to investing in research on crops

NCRI scientist Dr Emmanuel Abo (in front) visits IITA's Biotechnology Laboratory to learn and apply up-to-date techniques of rice virus diagnostics, assisted by Mr Segun Akinbade, IITA virology technician.

such as cowpea and yams, where the total area cultivated is small and farmers keep their own planting material and have little or no money to spend on seed and other inputs. Firms may be prepared to share genes and patented technologies, free or at minimum cost, with publicly funded research organisations in developing countries in order to generate international public goods. However, they will usually impose strict conditions to ensure that these technologies do not find their way into competing products or markets.

Whether or not they generate technologies relevant to improving tropical crops, publicly funded institutions in the North may depend on patenting and marketing such innovations as a supplementary source of research and development funds. Indeed, the intellectual property issues surrounding innovation in biotechnology can become so complex that they alone come to constitute a significant obstacle to progress, especially in the public sector and in developing countries. Evidently there is tremendous scope for Gatsby, in collaboration with institutions such as ISAAA (see Chapter 5, p. 40) and the international research centres, to contribute to the transfer of promising biotechnology products to developing countries and to help ensure that these products are used to good effect. This is a continuously evolving field and one in which the rulebook is still being written; however, biotechnology could have a tremendous impact on prosperity and food security in Africa and so surely deserves further 'constructive engagement' on the part of Gatsby.

Projects in brief

Yam virus diagnostics (*D. alata*)

Partners: JIC, HRI and IITA.

Timescale: 1994–1996.

Aim: To develop virus indexing procedures for *D. alata.*

Rationale: Water yams in West Africa are infected by several viruses, but the lack of adequate diagnostic tests obstructs the movement of germplasm.

Progress:
- Samples of leaves and tubers of *D. alata* collected in four West African countries indicated that two viruses were prevalent: *Dioscorea alata* bacilliform virus (DaBV) and *Dioscorea alata potyvirus* (DaV).
- Limited characterisation studies indicated that DaBV is mealybug-transmitted and restricted to *Dioscorea* species.
- Specific polyclonal antisera to DaBV were prepared.

Yam virus variability (*D. rotundata*)

Partners: NRI and IITA.

Timescale: 1994–1999.

Aim: To develop robust diagnostic tests for the major yam viruses prevalent in West Africa.

Rationale: Various yam viruses were known or believed to be prevalent in West African yams, but the inadequacy of existing diagnostics impeded the safe exchange of germplasm, breeding efforts and epidemiological studies. Variability is a key issue in virus diagnostics, as an improved test must not only be more sensitive than existing ones but must reliably detect as many variants of each virus as possible.

Progress:
- Investigation of a large number of samples indicated that infections in cultivated yams in West Africa are attributable to *Yam mosaic potyvirus* (YMV) or *Dioscorea alata potyvirus* (DaV).
- Highly conserved sequences were identified and used to develop an IC-PCR test, 100 to 10 000 times more sensitive than existing ELISA tests.
- Field testing of kits using dried reagents showed tests to be robust and reliable.

Note: This project was initially intended to focus on potyviruses, especially of *D. rotundata*, but broadened in scope during its second phase.

Developing resistance to yam viruses

Partners: IITA.

Timescale: 1997–2001.

Aim: To identify sources of resistance to yam viruses and elucidate inheritance of resistance to *Yam mosaic potyvirus* (YMV) in *D. rotundata.*

Rationale: Aphid-transmitted potyviruses, especially *Yam mosaic potyvirus* (YMV), were believed to be a major source of yield loss in cultivated yams. Some cultivated clones and wild species were believed on the basis of symptoms to be resistant or tolerant. New diagnostic tests offered the possibility of investigating the relationship between virus infection, symptoms and losses, looking for sources of resistance and elucidating the nature and inheritance of resistance.

Progress:

- Numerous varieties and species were tested for their reaction to potyviruses by artificial inoculation, screenhouse tests and multi-site trials.
- Four additional species of aphids were confirmed as vectors of YMV (making a total of eight).
- Various *Dioscorea* species were identified as asymptomatic hosts, providing a reservoir for infection.
- Resistance to YMV in *D. rotundata* was attributed to at least two dominant genes.

Developing a genetic map of yam

Partners: IITA and JIC.

Timescale: 1994–2001.

Aim: To enhance breeding efforts in yams by elucidating the nature of the yam genome and evolutionary relationships among *Dioscorea* species and varieties.

Rationale: Yams were an important staple food with considerable scope for improvement through selective breeding, especially for increased resistance to diseases and pests. Yams existed as separate male or female, vegetatively propagated clones. Germplasm accessions were poorly characterised and crossing experiments were obstructed by difficulty in obtaining synchronous flowering and fertile seed, as well as the long growth period before progeny can be evaluated. Molecular techniques would increase the likelihood of successful crosses, both among cultivated varieties and with related wild species, in pursuit of additional traits not found in the limited genepool of cultivated yams.

Progress:

- Yam germplasm was characterised using morphological characters, isozymes and DNA markers.
- Cultivated yams were shown to be polyploids (mostly tetraploid) with a basic chromosome number of 10.
- Preliminary linkage maps were derived for both *D. alata* and *D. rotundata*, covering some 50 to 60% of the genome.
- Some information was made available on the segregation of disease resistance.

Developing a genetic map of cowpea

Partners: JIC and IITA.

Timescale: 1994–2001.

Aim: To enhance breeding efforts for resistance to insects, viruses, *Striga* and environmental stresses by developing a map of the cowpea genome.

Rationale: Cowpea was a key crop in West Africa, both nutritionally and as a component of sustainable cropping systems for marginal areas. Yields were low due to severe losses to pests, diseases and parasitic plants. Selective breeding had made great progress in alleviating biotic constraints, but several remained to be adequately addressed. Developing a genetic map of cowpea would speed selection for resistance to these constraints and would enhance the options for breeding for drought tolerance, day-length sensitivity and other characteristics.

Progress:

- A linkage map of cowpea was developed using RAPDs, AFLPs, short sequence repeats (SSRs) and morphological attributes.
- Markers associated with QTLs for bruchid and thrips resistance were identified.
- DNA markers were converted to SCARs, which can be used for marker-assisted selection.

Transformation of cowpea for insect and virus resistance

Partners: JIC and IITA.

Timescale: 1994–1999.

Aim: To develop insect- and virus-resistant cowpea through transformation, using insect resistance genes from wild *Vigna* species and viral coat protein genes.

Rationale: Despite a concerted conventional breeding effort, good sources of resistance to post-flowering pests of cowpea, especially *Maruca* and pod-sucking bugs, had not been found and the risk of severe losses to these pests discouraged the adoption of improved cowpea by farmers. Adequate resistance to two viruses (CABMV and BCMV) had been developed in West Africa but had broken down when these varieties were disseminated in Southern Africa, resulting in severe losses. Successful transformation of other legumes provided grounds for believing that these problems could be solved by bringing in genes from other *Vigna* species and from the target viruses.

Progress:

- Experienced was gained with cowpea transformation protocols, but only transient expression of introduced genes was obtained.
- Highly conserved parts of the genome of the two target viruses were identified and constructs that were expected to confirm durable virus resistance were prepared.

Transformation of *Musa* for resistance to Banana streak virus

Partners: JIC and IITA.

Timescale: 1998–2002.

Aim: To develop banana and plantain plants resistant to BSV.

Rationale: BSV was a very widespread pathogen of banana and plantain, which in some places caused serious losses in yield. No sources of resistance to BSV were known within *Musa* germplasm, while long generation times and other technical problems in any case hindered the search for resistance by conventional breeding. Over recent years a novel way of conferring virus resistance had been established for several crops that involved introducing a fragment of the virus genome into that of the crop. This resulted in disruption of virus replication and protection of the plant from disease. Knowledge of the necessary techniques and of the BSV genome at JIC combined with successful optimisation of *Musa* transformation protocols by KULeuven and others suggested that this approach would be feasible for protecting *Musa* against BSV.

Progress:

- Virus sequences shared between many variants of BSV (and thus expected to confer durable resistance) were identified.
- Sequences of suitable constructs for transformation were defined.
- A protocol for *Agrobacterium*-mediated transformation and regeneration of *Musa*, using reporter genes, was optimised.

Biosafety

Partners: IITA.

Timescale: 1998–2002.

Aim: To encourage the development of sound policies related to genetically modified crops in West Africa.

Rationale: Several genetically modified crops that could contribute significantly to development objectives were available or were about to become available in West Africa. Their biosafety testing and deployment would be severely delayed in the absence of an adequate statutory and policy framework. This project was intended to raise awareness among regional decision-makers of the key issues relating to the use of genetically modified crops and so to encourage them to take the necessary action to use this new technology effectively.

Progress:

- A major regional workshop was convened in February 2002, bringing together diverse interested parties from Nigeria, Benin, Burkina Faso, Cameroon, Ghana and Niger.

7. The value of knowledge: farmers and scientists learn how to manage the maize production environment

From basic biology to profitable farm management

Farmers in Suba District, on the Kenyan shore of Lake Victoria, do not have an easy life. Despite the vast expanse of fresh water nearby, this is an area of low and uncertain rainfall, in the 'rain shadow' of the country's western highlands. There is some good black soil, suitable for growing cotton, but the roads are poor and it is a long way to take produce to markets or to buy inputs. Traditionally, most of the district's people have eked out a living from fishing and from growing cassava, sorghum or other drought-tolerant subsistence crops. However, the population of the Lake Basin is growing, putting pressure on the more fertile land. And small-scale fishing has been hit, first by the intentional introduction of Nile perch to Lake Victoria and then by the accidental introduction of the water hyacinth. Many people, needing cash to send their children to school and to provide a better life for their families, are turning to more intensive farming to increase their income. The Kenya government's successful efforts to eradicate tsetse flies and trypanosomiasis from the Lambwe Valley, in the heart of Suba District, have opened up land for both arable and livestock farming, but individual farmers are finding it hard to translate their new land and hard work into improved livelihoods.

The case of Mrs Albeta Waga Adede, pictured here with Mrs Pamela Liech, the Lambwe Divisional Crops Officer, is not unusual. 'When the rains came, I first planted my best field to cotton—it's the most profitable crop here,' she said. 'But then we suffered a drought.' The uncertain rainfall that slowed the early growth of her cotton had an even more severe impact on the maize she had planted next, as a second source of income and to feed her family. The weakened, late-sown plants were heavily attacked by stemborers—caterpillars that tunnel in the stems of almost all cereal crops in the tropics. The leaves of the plants were soon discoloured by Maize streak virus and, when the cobs appeared, many were grotesquely deformed by corn smut fungus. As the field matured, the pink flower spikes of the parasitic 'witchweed' (*Striga hermonthica*) were as abundant—and a good deal stronger—than the sickly maize plants. The Crops Officer helpfully suggested that next year Waga should buy certified maize seed from the Kenya Seed Company, to avoid the risk of seed-borne diseases, and that she could raise yields further if she planted the seed in a timely manner and applied fertiliser. But, apart from being desperately short of cash to invest in such inputs, Waga was in need of a much more comprehensive overhaul of her farm and her approach to farming: she needed to rebuild the fertility of her soil and the health of her crops; and she needed to gain the knowledge that would equip her to avoid or combat the seemingly relentless tide of pests and diseases more effectively in the future.

Fortunately for Waga, by the time this photo was taken in 2000, researchers at the nearby

Stemborers were just one of several problems that afflicted the maize plot of Albeta Waga Adede (right), pictured in discussion with extension agent Pamela Liech.

Mbita Point field station of ICIPE had already been working for several years, with Gatsby support, on developing the elements of a solution. Indeed, a farmer research group and field school,

Stemborer caterpillars are the larval stage of certain species of moths, such as Chilo partellus, Sesamia calamistis *and* Eldana saccharina. *They attack not only cereal crops (maize, sorghum, millet, rice, etc) but also other plants in the grass family, such as sugarcane and wild grasses.*

established by ICIPE and its partners in the nearby village of Ogengo, was already fine-tuning for local conditions, and helping farmers to adopt, a new integrated production system founded on this research. Based on the so-called push–pull approach to insect pest management, the new system offers farmers the chance not only to raise their maize yields through better protection against pests but also to restore soil fertility and rid their land of witchweed.

When Gatsby began supporting ICIPE's research on maize stemborer in 1994, push–pull was little more than a promising idea in the minds of an informal global network of chemical ecologists. By the time Waga joined her local farmer research group, the scientists' idea had evolved into a practical technology that was already starting to improve the lives of several hundred farmers in western Kenya. As this report goes to press, farmers in at least five other African countries are trying out their own version of the technology, adapted for their own needs and situation. Part of the project, concerning insect repellents and attractants, has evolved along classical lines, starting with the generation of basic knowledge about a biological system, translating that knowledge into a practical technology, and then empowering farmers, by teaching them about farm ecology, to adapt and adopt the technology to their various needs. Along the way, the quest for knowledge, coupled with a flexible approach to research funding and management, has led to some remarkable discoveries about parasitic plants that have increased the practical value of the project far beyond the scientists' initial expectations.

Elements of a lasting solution

The key to providing robust, durable solutions to problems like Waga's lies in understanding the complex relationships between plants, pests and their habitat. When ICIPE was established, its founding Director, Prof Thomas Odhiambo, resolved to build an institution that would not merely test and transfer technology based on the science of others but would also develop the capacity to carry out basic research—research that would generate the new knowledge necessary for tackling the pest- and vector-related aspects of Africa's most pressing crop, livestock and human health problems. Although ICIPE's agenda has evolved over the years, and its strategy now stresses scientific partnerships rather than self-reliance, the tradition of open-ended enquiry that characterises basic research is reflected in this story of how studies of pest and natural enemy behaviour led researchers to find solutions to a whole series of inter-connected farm-level problems.

Stemborers, the larvae of various species of moth, are the major insect pests of maize in Africa. Under natural conditions, these insects feed on wild grassy plants, and until the introduction of maize from Latin America, they were of no special consequence. When farmers began to grow maize and sorghum as crops across vast areas of Africa, stemborers adapted to feed on these cultivated relatives of their host plants. The large stems and comparatively weak chemical defences of the crop plants provided an excellent breeding ground and protected the insects from their major natural enemies—tiny parasitic wasps that, in wild grasses, are highly effective at locating and attacking the stemborers. As a result the stemborers flourished and became a problem of major economic importance. Today, yield losses to stemborers average 20%, but can reach 80% in some areas. Applying pesticides not only represents a potential health risk for the farmer and a threat to the environment but is also rarely cost-effective.

Traditional cereal-based farming systems in Africa usually involve intercropping maize, sorghum or millet with another crop, such as beans or cowpea, or indeed a whole range of vegetables, most of which are not suitable host plants for stemborers. There are, however, plenty of grasses in such a system—both as weeds in the crop and as the dominant vegetation in adjacent natural fallow areas. As farmers intensify production, both weeds and fallow areas are reduced. In 1994, the ICIPE team began working with scientists at the UK's Institute of Arable Crops Research (IACR)–Rothamsted to test the hypothesis that wild grasses might attract the pest and could be intentionally managed as a 'trap crop'. 'Stemborers prefer to lay their eggs on their natural host, which is wild grasses,' says Dr Zeyaur Khan, leader of ICIPE's maize habitat management project.[1] 'But they don't have to do so. We used to think that weeding out the grass would get rid of the stemborers, but in fact the opposite is the case, since they transfer to the maize.' Grassy weeds growing among the cereal crop provide too much competition, but when researchers planted wild species such as Napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum sudanense*) in a border around the maize fields, the stemborers were attracted to lay their eggs here, providing the 'pull' in the push–pull strategy. Napier grass has a particularly effective way of defending itself against attack: when the larvae bore into the stem, the grass secretes a sticky gum, physically trapping the borer and preventing most larvae from completing their life cycle. The grasses also provide a haven for the borer's natural enemies, such as the parasitic wasp *Cotesia flavipes*. Besides increased maize yields, the farmers planting a border row benefit from a ready supply of grass to feed their livestock or sell to other farmers.

Plant defence chemicals can also 'push' the pests out of the crop. The push can be provided by the plants growing among the cereals, but intercrops do not necessarily reduce pest infestation. 'We needed to find out which compounds produced by the cereals, intercrops and wild grasses were attractive to the insects and which were repellent,' recalls Prof John Pickett, a collaborating researcher at IACR–Rothamsted. Pickett has special expertise in identifying the volatile 'semiochemicals' that plants and insects use to communicate with one another. He and his colleagues first separate complex natural mixtures of chemicals in a fractionating column, then use mass spectrometry to identify those that elicit a response in the insect under investigation. Working in parallel on different aspects of the problem, the researchers in Kenya and the UK were intrigued to find that chemicals from another fodder plant, molasses grass (*Melinis minutiflora*), not only repelled female stemborer moths but also attracted the parasitic wasp *Cotesia sesamiae*. The results of this Gatsby-supported work were striking enough as scientific insights to be published in the leading international journal *Nature*.

When scientists exploit the chemicals produced by plants and use them to push and pull pests and beneficial insects into or out of the crop, they make use of balancing mechanisms that already exist in nature. 'Push–pull is not something scientists have invented,' says Dr Ahmed Hassanali, Head of the Behavioural and Chemical Ecology Department at ICIPE. 'It happens everywhere in nature as an active attraction or avoidance strategy. It is a recurring theme because it is so efficient.' What the scientists have done is to identify and exploit these phenomena, consciously assembling a series of complementary tactics that should prove more effective and durable than a single pest control strategy used alone (see box, overleaf). As such, the approach fits well with the philosophy of integrated pest management (IPM), which makes full use of the natural processes that regulate pest populations, combining host plant resistance, biological control and habitat management strategies—and resorting to chemicals only if these methods fail to keep populations below damaging levels.

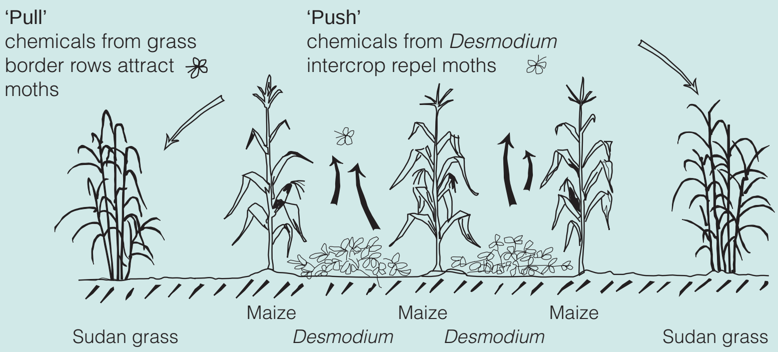
Responding to farmers' needs

Bearing in mind that the push–pull approach would require farmers to make big changes in the way they manage their farms, members of ICIPE's research team were sensitive to the need for on-farm participatory research to adapt the scientists' proposals to the practical needs of the farmers.

[1] The full title of this project is: Implementation of Habitat Management Strategies for the Control of Stemborers and *Striga* in Maize-based Farming Systems in Eastern Africa and Mechanisms of *Striga* Suppression by *Desmodium* spp.

Options for biochemical control

The idea of the ‘push–pull’ approach—or ‘stimulodeterrent diversionary strategy’ as the scientists call it—arose from discussions among insect behaviourists and chemical ecologists in Australia, the USA and the UK. Concerned that promising IPM tactics based on semiochemicals too often fail because they are too narrowly based (typically a single product, targeting one point in the life history of a single pest species), the researchers agreed that it would be advantageous to develop more comprehensive systems, making use of a wider range of behaviour-affecting chemicals produced by plants and insects. For instance, the research team at IACR–Rothamsted looked at various strategies, exploiting naturally occurring chemical repellents and attractants, for managing aphids in crops of oil seed rape. The ICIPE work on cereals and grasses fitted perfectly into this conceptual framework and gained from the procedures and equipment already set up for similar work.



The combined ICIPE–IACR team found that natural stemborer damage could be greatly reduced by managing the environment and introducing a carefully selected combination of companion plants. When maize plots were surrounded by border rows of tall fodder grasses, volatile chemicals from Sudan grass or Napier grass attracted the stemborers more strongly than maize, with the result that numerous eggs were laid on these ‘trap crops’ and fewer than normal were laid on the maize. Large numbers of stemborer progeny were not, however, produced. In the case of Napier grass, this was because the plant’s own defence mechanisms killed the developing larvae, but in Sudan grass it was because large numbers of natural enemies arrived to parasitise the borers. Molasses grass, on the other hand, produces chemicals that are so repellent to adult stemborer moths that no eggs were laid on the molasses grass itself and few on the adjacent rows of maize. The effect was strongest with alternating rows of maize and molasses grass, but was still detectable with 1 row of molasses grass for every 10 of maize!

Chemicals from the molasses grass also attract female parasitic wasps, despite the absence of stemborer larvae for the wasps to parasitise. Scientists postulate that this grass produces unusually high levels of compounds that are normally produced by damaged cereal plants in response to pest attack. At low levels of the chemicals, additional pests arrive, ‘expecting’ to be able to exploit a plant already weakened by pest attack, but at high levels the pests are repelled, perhaps taking it as a sign that the plant is already fully exploited; at low or high levels, parasitoids arrive to find their prey. Thus the subtle cues that insects use to find plants or each other can be employed by plants in their evolutionary arms race with insects—or can be used by humans wishing to manipulate plants and insects alike!

Parasitic ‘witch-weed’, Striga hermonthica*, has attractive flowers but is the scourge of maize and sorghum production in much of Africa.*

This phase of the work was also supported by Gatsby. ‘We focused on fodder crops as these give farmers an added incentive to plant them,’ says Khan. Two fodders were found to have the desired characteristic of repelling stemborers: molasses grass and *Desmodium*, a low-growing forage legume that was already being used by a few Kenyan farmers as a nutritious fodder for stall-fed dairy cows. Although molasses grass is better at repelling the stemborer, *Desmodium* is preferred by cattle, has a high protein content and improves soil fertility due to its ability to fix nitrogen.

But the scientists soon discovered that *Desmodium* had another, unexpected benefit. ‘We were testing our “push–pull” habitat management approach at several sites in western Kenya,’ recalls Khan, who is also leading the on-farm research. ‘The farmers here suffer greatly from *Striga*, which devastates maize fields and is very hard to get rid of. Yet, to our surprise we found that, when intercropped with *Desmodium*, the maize fields became virtually free of *Striga* after only two seasons' (see box). Indeed, getting rid of the *Striga* had an even bigger effect on increasing maize yields than controlling the stemborers.

Results like these are exciting, but the team was justifiably cautious. For farmers to undertake the radical overhaul of their farming practices that the push–pull approach implies, it was vital that they fully understood the underlying mechanisms. This understanding would also allow them to adapt the approach to their own needs and to changing conditions in the future. Demonstration plots and free planting materials helped illustrate the benefits and served as the basis for explaining key ideas such as biological control and the biology of parasitic weeds. Meanwhile, training in scientific methods encouraged farmers to experiment further, gain ownership of the technology and pass on their new knowledge to others. A useful innovation that some farmers have made is to align the plantings of

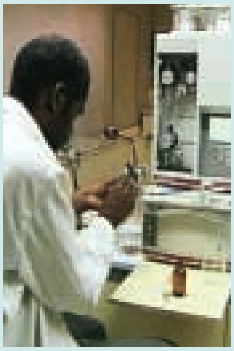
ICIPE project leader Zeyaur Khan shows how intercropping Desmodium *with maize (in the foreground) has produced a healthier maize crop and cleared the land of* Striga *(seen as the pink flowers in the conventionally cultivated plot behind).*

The witches' curse and the *Desmodium* miracle

The seeds of *Striga* are so tiny that farmers often unwittingly bring them into their fields and sow them along with their crops. Stimulated by exudates from the roots of the crop, the seeds germinate—but instead of growing roots and drawing nourishment from the soil, they parasitise the crop, weakening or even killing it. Over the years, healthy crops are replaced by the pink flowers of *Striga* and the field seems cursed by these so-called 'witchweeds'. Each plant produces up to 50 000 seeds, which can lie dormant for 10 years or more, waiting for a suitable host crop to be planted. Deteriorating soil fertility favours the growth of *Striga* and the survival of its seeds so that, before farmers know it, they are trapped in a vicious cycle of declining yields, increasing poverty and hunger—and reduced strength and will to tackle the problem.

Discovery of the 'miracle' plant *Desmodium* has transformed the way *Striga* is managed. Simply sowing rows of the forage legume as an intercrop with maize results in the virtual elimination of *Striga* after just two seasons. But how does *Desmodium* stop *Striga*? Colleagues at ICIPE and IACR–Rothamsted have been investigating this intriguing question over the past three years. Scientists have known for some time that carefully selected varieties of legumes such as soybean and cowpea not only improve soil fertility but also cause the 'suicidal germination' of *Striga*—producing the same chemicals as cereal hosts that stimulate the parasite's germination, but not acting as a satisfactory host. *Desmodium* seems to exert an even stronger effect, stimulating *Striga* to germinate in the same way but simultaneously releasing an inhibitor into the soil, which arrests the growth of the parasite's 'haustorium'—the structure which the *Striga* seedling would normally use to attach itself to its host.

The chemistry is very complex, but understanding it may help scientists to develop other control options for the various *Striga* species that attack other cereals, sugarcane and cowpea. Identifying the chemicals involved may also help to develop control options for other parasitic plants such as *Orobanche*, which attacks grain legumes and vegetables, and *Alectra vogelii*, which affects groundnut and cowpea.



Doctoral student Mr Muniru Khamis Tsanuo collects root exudates from Desmodium *grown in a glasshouse at ICIPE, Nairobi, and uses gas chromatography to help identify compounds that might be arresting* Striga *parasitism.*

Napier grass with the rows of maize, so that ploughs drawn by oxen can pass in at least one direction through the border rows of trap crop. Other farmers, who find the perennial *Desmodium* difficult to manage or who do not have a ready market for this fodder, are testing beans or groundnut as possible alternative legume inter-crops. The continuing interaction with ICIPE staff, who are always there to answer questions and provide other forms of technical backstopping when needed, has been a key element in the farmers' success—and was also made possible by the Gatsby grant.

Mr Laurence Odek, leader of the farmer research group in Ogengo. One of ICIPE's lead farmers, Odek is carrying out his own experiments on stemborer and Striga *management. Here he tests the effects of substituting field beans for* Desmodium. *He has dedicated part of his farm for use as a research and training area, for the benefit of some 25 farmers who come here to learn from him and from the researchers.*

Turning a tidy profit

Word spread quickly and soon farmers from all over Suba District were clamouring for *Desmodium* seed, creating a serious supply problem. The Kenya Seed Company was importing seed from Australia, but there was clearly a need to increase local supplies. Gatsby responded by providing additional funds for a seed multiplication project. Several women's groups have started multiplication centres, planting the *Desmodium* as a monocrop in order to maximise production. The seeds fetch a high price in the market (US$ 15–20 per kg), providing a valuable new source of income for these women. The ICIPE team are now investigating different species of *Desmodium* and alternative production sites, with a range of soil and climatic conditions, to find out which are best suited to seed production.

Market forces play a vital part in encouraging or discouraging the adoption of environmentally friendly technologies. Though the farmers in the Lambwe research groups recognised the value of the push–pull approach in controlling stemborers and *Striga* and so boosting their maize production, many of them cited the additional income-generating opportunities offered by the forages as the main incentive for switching to the new system. There is a shortage of milk in the pilot area and indeed a shortage of good-quality forage to support dairy cows. The sale of both Napier grass and *Desmodium* to neighbours with stall-fed cattle has provided an important new source of income for arable farmers in the research groups—all the more important because the forage can be harvested at times when there is no grain from the main cereal or pulse crops to harvest and sell. Some farmers have made enough profit from the sale of fodder to buy a dairy cow themselves, providing a quantum leap in their potential income and in the nutritional status of their families. Conversely, in areas where traditional arrangements allow pastoralists to graze cattle on the residues of arable crops, the fact that the cattle also tend to consume any perennial fodder crops, without benefit to the arable farmer, makes the new system a less attractive proposition. Although the dairy market is such a vital ingredient in the success of the maize habitat management project, the credit to buy dairy cows and the expertise to manage them are provided in Suba District by another development project with no formal links to Gatsby and its partners. Such constraints and opportunities are well-nigh impossible to foresee at the project planning stage, underlining the need for flexibility and imagination during project implementation.

Broader horizons, new challenges

Overall, the adapted push–pull system seems to work well for farmers on the Kenyan shore of Lake Victoria. At least 600 of them are now involved in evaluating and using the technology. All are small-scale producers who have the greatest need to improve their productivity and standard of living.

And the word is still spreading from farmer to farmer, as well as through the formal efforts of extension organisations. The key question now is how widely the technology can be applied elsewhere in Africa. To what extent must the technology be adapted to each local situation and how can the process of adaptation and adoption best be facilitated?

With Gatsby's help, the ICIPE team is linking with national scientists to evaluate or introduce the technology on an experimental basis in South Africa, Uganda, Ethiopia, Tanzania and Malawi. In the process, the project partners have learned important lessons: local needs—and therefore the nature of the solution—can be very different and continuing scientific input is needed to underpin the process of evaluation and adaptation.

In South Africa, for instance, a scientist based first at the Agricultural Research Council and then at the University of Potchefstroom has worked with colleagues at the University of the North, in Pietersburg, and with staff of the provincial agricultural department to explore the use of the technology in the country's Limpopo Province (formerly Northern Province). At first centred around Pietersburg itself, research has recently been extended to the Tschiombo irrigation scheme and the Spitskop area, as well as parts of Kwazulu Natal Province, where a number of well established local NGOs have joined the effort, including the Valley Trust, the Heifer Project and the Institute of Natural Resources. At each location the researchers have investigated farmers' perceptions of the damage caused to cereal and other crops by different insect pests and weeds, completed surveys on the wild host plants of stemborers and other pests, and assessed local crops, crop varieties, animal husbandry practices and other factors specific to the local farming system. Several crucial differences have emerged among locations, underlining the value of undertaking such preparatory work with farmers.

Unlike in western Kenya, stemborers are not perceived as a major problem around the Pietersburg area, where the main benefit from

Mrs Omulo is one of the project farmers who is using the high-value fodders from her maize pest management plot to feed dairy cows.

planting wild grasses around a maize plot appears to be the prevention of soil erosion.[2] In addition, there is less need for fodder crops here, as few cattle are kept and they are seldom stall-fed. In Kwazulu Natal, where maize is an important food staple grown by small-scale farmers, the collaborative team is assessing the efficacy of intercrops such as cowpea, which also has intriguing push–pull properties, in addition to Napier grass and Vetiver (*Vetiveria zizanioides*), another grass species grown locally. The mixed crop–livestock farmers of this area are expected to appreciate the value of the improved system's fodder components. The next two years will determine the value of the habitat management approach in the South African context.

In Uganda and Ethiopia, the pest constraints appeared broadly similar to those in Kenya, but early results of field trials suggested that the technology was not working. It turned out, however, that the problem lay not in the technology itself but in the experimental design of the trials. Exchange visits and enhanced communication between ICIPE and national scientists were able to resolve the problem, but the experience has shown the need for good backstopping wherever this new approach, unfamiliar to national researchers, is introduced. The crucial importance of good scientific method and professional integrity is underlined by Pickett of IACR–Rothamsted: 'In a research network of this kind, it's vital that the partners achieve a

2 The occurrence of severe drought during the surveys may have affected farmers' perceptions. Farmers reported the populations of all insect pests to be low during this period. Drought also affected the establishment of Napier grass in on-farm trials.

common high level of experimental design and data analysis. An institution like Rothamsted, with its extensive experience and international contacts, is ideally placed to help ICIPE and its partners achieve this level of scientific excellence.'

The work in Uganda is now going well and in April 2001 NARO scientists began to introduce the technology to farming communities in the east of the country. They selected study sites in major maize-producing areas, where stemborers and *Striga* are significant problems and where livestock are kept. Four sites in different agro-ecological zones have been established and the researchers have visited farmers, identified problems and exchanged visits with ICIPE staff. The communities used a participatory approach to select farmers to host evaluations and demonstrations during 2002. Learning from their Kenyan counterparts, they have already identified shortage of *Desmodium* seed as a potential constraint, and are setting up seed production centres in anticipation of increasing demand. Meanwhile, by way of scientific backstopping, oviposition choice tests have been conducted at NARO's NAARI, to see which candidate fodder grasses the local stemborers find most attractive for laying their eggs. 'There is no universal solution,' explains Dr William Overholt, leader of ICIPE's Staple Food Crops Programme. 'Species and populations of stemborers vary from country to country and may well behave differently. There will always be a need to adapt the technology to local ecologies and socio-economic conditions, and this requires adequate scientific input.' This indispensable research is expensive, however, and its cost must be allowed for in any attempt to scale out the technology to achieve broader impact.

The way ahead

'This project is unique in the way it has developed from pure science through to farmer uptake and spontaneous technology transfer,' says Khan. Linking 'science' with farm-level 'impact' is a deliberate feature of many Gatsby projects, as is a readiness to follow up on new opportunities as they arise. The continuity of Gatsby funding since the project started in 1994 has been an important element in the successful transition from research to development. 'We value this commitment to exploratory research,' adds Hassanali. 'Many major scientific breakthroughs have happened by accident, so it's important that donors do not set project boundaries too rigidly. Understanding the chemistry of parasitic weeds is a good example: research may not yield immediate benefits, but the final impact could be huge.'

Some analysts have challenged the long-term benefits of this technology and the associated research-intensive approach to technology adaptation and dissemination on which its success depends. It has been suggested, for example, that transgenic maize with in-built resistance to stemborers and *Striga* will be the ideal solution of the future and that, since the technology is 'built into the seed', this will largely circumvent the need for relatively expensive participatory research and training efforts. However, such objections miss a vital point about this integrated R&D approach: the key product of this investment is not so much a pest management technology, important though this is, but more the knowledge of farm ecology and the tradition of working together to solve problems that are generated, among researchers, extension workers and farmers alike. This knowledge, together with the experiment-and-innovate approach, empowers all the partners, not just to cope with *Striga* and stemborers now, but to tackle other challenges and opportunities that will arise in the future.

This environmentally and socially sustainable approach has not only met with wide acceptance from farmers but is also one that other donors find attractive. ICIPE's maize habitat management programme is now attracting substantial co-funding from other sources, including USAID, the Rockefeller Foundation, the International Fund for Agricultural Development (IFAD) and a private Swiss foundation. The applicability of the approach to a broader set of pest problems in other crops remains to be explored.

Projects in brief

Maize habitat management

Partners: ICIPE, IACR–Rothamsted and national partners.

Timescale: 1994–2004.

Aim: To examine the interactions between cultivated crops, wild hosts, stemborer species and natural enemies affecting the dynamics of pest populations with a view to developing effective pest management strategies.

Rationale: Maize and sorghum are important staple cereal crops in Africa and economic damage due to stemborers is on the increase. Study of the dynamic relationship between populations of stemborers in wild host plants and cultivated crops is important for the development of a sustainable IPM approach.

Progress:

- The push–pull technology had been adopted by 1500 farmers in western Kenya by the end of 2002.
- The technology has been introduced on an experimental and/or pilot basis in Ethiopia, Malawi, Tanzania and Uganda.
- Major progress in *Striga* control has been achieved by intercropping maize with *Desmodium.*
- A better understanding has been developed of the chemical basis for stemborer attraction and *Striga* development.

Maize habitat management in South Africa

Partners: Agricultural Research Council, Potchefstroom University, University of the North (Pietersburg), Heifer Project, Valley Trust and Institute of Natural Resources (Pietermaritzburg).

Timescale: 1999–2005.

Aim: To examine the interactions between cultivated crops, wild hosts, stemborer species and natural enemies affecting the dynamics of pest populations with a view to developing effective pest management strategies in Limpopo and Kwazulu Natal Provinces.

Rationale: Maize and sorghum are important staple cereal crops in Africa and economic damage due to stemborers is on the increase. Study of the dynamic relationship between populations of stemborers in wild host plants and cultivated crops is important for the development of a sustainable IPM approach. In addition, grasses such as Napier are useful for soil conservation and as fodder crops for livestock.

8. Conclusions

The evolving context: action across a spectrum

This report has shown how Gatsby's original objective, of raising the yields of key crops through technology transfer, has broadened to encompass a spectrum of R&D activities while still remaining geared to the dissemination of new crop varieties and other products of agricultural research. The spectrum now ranges from strategic research (some of considerable sophistication), needed to build the stock of useful knowledge, through applied research to develop new technologies, to adaptive on-farm activities, which fine-tune technologies to local circumstances and so secure adoption. Activities relating to technology dissemination have often been accompanied by institutional development, which has proved to be another vital condition for achieving widespread adoption (see box, overleaf). Experience has shown that action across the spectrum, whether this is assured by Gatsby alone or by a consortium of donors, is needed to achieve real improvement in the lives of producers and consumers.

During the 17 years over which the Gatsby programme has evolved, the international debate on research and technology dissemination in agriculture has taken a direction that was not easily foreseeable in the mid-1980s. The work of the international agricultural research centres and of national agricultural research programmes was always at least partly premised on the need for farmers to be involved in assessing new crop varieties and crop management systems. However, the current enthusiasm for farmer-led research is the culmination of a trend towards ever-greater involvement of farmers in the research process itself. The experience of Gatsby and its partners suggests that this trend may have gone too far and that a balance should be struck which recognises the interdependent but distinct roles of research scientists, extension workers and farmers. Certainly, the experience suggests that successful research—research that brings a marked improvement in productivity and livelihoods—requires innovations from the formal research sector—something that some forms of farmer-led research explicitly reject.

It is also appropriate to question the respective roles of the international centres and the national programmes as partners in the agricultural innovation process, not so much because the current system has failed but rather because new options for international collaboration have arisen, notably that of placing increasing reliance on the private sector as a supplier of both technology and services. In fact, the record of the Gatsby projects suggests that these partnerships have continued to provide products of value to small-scale farmers over the period in which the Foundation has been active in the sector. Nevertheless, developing new models for international collaboration in agricultural research is an important theme on which Gatsby's experience also sheds some useful light.

The Gatsby portfolio of projects now represents a substantial investment in institutional development. Whilst the Foundation had not originally intended to support this aspect of technology dissemination, early experiences with the cassava projects in Cameroon and Uganda (see Chapter 2) confirmed the need for such involvement. During the 1990s the combined effects of economic liberalisation, stringent limits on public expenditure and new thinking on the adoption of technology by farmers increased the need for investment in institutions still further. Indeed, it became imperative to find new ways of providing institutional support to the small-farm sector, which in many countries fell into a steep decline following the withdrawal of government

Gatsby projects in African agriculture and the R&D spectrum

Project/activities	Strategic/applied research	Adaptive research	Dissemination with farmers	Institutional development[1]
IITA–IRAD Cassava dissemination		✓	✓	✓
NARO–IITA Cassava dissemination		✓	✓	✓
NARO–CIAT Beans		✓	✓	✓
WARDA and partners Rice		✓	✓	✓
ISAAA and partners Improved trees		✓		✓
NARO Banana management		✓	✓	✓
IITA–JIC Banana virus diagnostics	✓			✓
IITA–JIC Yam virus diagnostics	✓			✓
IITA–JIC Yam mapping	✓			
IITA–JIC Cowpea mapping	✓			
IITA–JIC Cowpea transformation	✓			
IITA–JIC Banana transformation	✓	✓		
IITA and partners Biosafety				✓
ICIPE and partners Habitat management	✓	✓	✓	✓

[1] Related to credit, marketing, contract seed production, training and other activities.

support and subsidies for inputs. Although there have been some bold initiatives that have sought to reverse the decline, these for the most part remain isolated examples of what can be done when other institutions step in to fill the vacuum left by the retreat of the formal sector. In the vast majority of countries, inadequacies in institutional development and uncertainties in related public policy still constitute a severe constraint to the effective dissemination and adoption of the outputs of agricultural research.

The focus of the research funded by Gatsby has also evolved over the past 17 years, from increasing the productivity of a single crop (especially through varietal selection) to achieving a sustainable increase in the productivity of entire cropping systems. Although several variables may be important in this process, building up organic matter to counter the widespread decline in soil fertility is often of over-riding concern.

Managing the research process

Several of the projects discussed in this report involve Gatsby support to strategic research, including the use of biotechnology to generate new methods and products (as discussed in Chapter 6) and diagnostic research to understand ecosystem processes, leading to new strategies for managing the production environment (Chapter 7).

There can be no doubt that several biotechnology applications have already been of invaluable service to farmers: these include micro-propagation procedures, which accelerated the distribution of new varieties of bananas and yams (Chapters 4 and 6) and virus diagnostics, which allowed these materials to be distributed across Africa. Apart from this, the Foundation's experience suggests a number of conclusions about managing and enhancing strategic research.

First, it is important to have a flexible view on the outcome of the proposed research agenda. Thus, in the case of the maize habitat management project developed by ICIPE, it was hoped that a solution which 'pulled' stemborers out of the maize crop and into wild grasses might develop. It was not anticipated that an inter-related push–pull system might be identified, still less that one plant which provides the 'push' would also suppress a dangerous parasitic weed (*Striga*), and still less again that a major benefit of the technology would be its impact on the adoption of dairy cattle. Under a conventionally strict project management regime, another funding agency might well have rejected the proposal to finance any of these add-ons to the planned programme as being too speculative or involving too much 'mission creep'. However, in this case, there is no doubt that Gatsby made the right decision in continuing to support the open-ended flow of the work.

Another example of the benefits of flexibility lies in the outcome of the work on developing diagnostic techniques for BSV in *Musa*. Gatsby's willingness to pursue the investigation of a complex problem, beyond the immediate needs of 'virus indexing' for germplasm transfer, allowed the researchers to gain insights into the novel behaviour and variability of this virus. This understanding helped the project team to develop a sounder strategy for monitoring the spread of the virus and will pay long-term dividends in terms of more effective management of the disease. There is even the not-too-distant possibility of developing *Musa* varieties that are rendered highly resistant to BSV via the 'gene silencing' approach.

In contrast, the work on the transformation of cowpea, despite being sustained for more than six years, has not been successful. In this case, in assessing the original proposal, it would have been better to have gone beyond the question of whether the transformation of cowpea was feasible to ask the broader question: is the development of a genetically modified cowpea likely to be the most cost-effective route to combating *Maruca* and other insect pests? In 1994, IITA took the view that it had reached the limits of the potential of conventional breeding to address these constraints. In the light of subsequent developments, some described in this report, it seems that greater attention could have been paid to the possibility of developing an ecologically based habitat management approach. Experience with such an approach in maize-based systems may yield useful lessons to guide the design and implementation of future research on systems in which cowpea is a component. Identifying such lessons and making a start in this new research direction is an attractive option for the further development of the Foundation's portfolio.

The content of the IITA–JIC collaborative programme, designed in 1994, reflected the high expectations coupled with uncertain outcomes characteristic of advanced research in the early 1990s. The possible gains from the application of molecular biology to key tropical food crops appeared to be very high, but no single group or individual could claim special insight into where the greatest returns would be achieved. In this context the work programme agreed between JIC and IITA was sound, since it embraced five such projects and so increased the chance of success. However, in the context of international experience since that time there is good reason, in future, to relate advanced research of this kind to more specific and perhaps narrower objectives, wherever possible linked to existing crop-specific initiatives. At the same time, it will be important to retain Gatsby's refreshing lack of cumbersome project design and monitoring procedures, which is appreciated by all its partners.

At the other end of the spectrum are activities concerned with the adaptation of new technologies, through various forms of researcher- and farmer-managed trials, followed by a dissemination phase in which a proven technology is adopted by larger numbers of farmers. In the conventional approach to technology transfer, there were clear distinctions between, on the one hand, on-station and on-farm trials (both managed by researchers, though with some farmer input) and, on the other, the research and extension phases (researchers were sometimes involved in the latter, but mainly as observers). These distinctions have been blurred by the above-mentioned tendency to involve farmers ever-earlier in the R&D process and give them a more active role in managing on-farm trials. Gatsby projects have further contributed to this blurring of roles by giving scientists responsibility for managing at least the early stages of technology dissemination through 'researcher-managed extension'. The success of this approach shows that the dissemination of relatively simple technologies, at least, can be achieved by revitalizing, rather than bypassing, extension services. However, it is important to recognise that the process of disseminating new crop management systems is more complex, and therefore more resource-intensive, than that of disseminating new crop varieties. Other institutional tools, such as farmer field schools, may be needed to complement the existing practices of extension services and NGOs, but even then the challenges of scaling up and out remain daunting.

Participatory research and training are especially important in 'scaling out' knowledge-intensive technologies in the fields of integrated pest management and natural resource management. Here the Ogengo farmer research group in Kenya (see Chapter 7) learn about insect transmission of crop viruses.

Partnerships for research and dissemination

At an institutional level, there are useful lessons to be learned from the experience of building and sustaining the collaboration between IITA and JIC and that between ICIPE and IACR–Rothamsted. The two collaborative relationships form an interesting contrast since the first was multi-faceted (involving six individual sub-projects) while the second is specific to a single large project, the maize habitat management project. The difficulties encountered in the IITA–JIC relationship throw into question the validity of the more complex organisational arrangements adopted in this case. The relationship was always likely to be undermined by the possibility that different collaborating partners might have been more appropriate for particular activities. Thus an institute such as IITA could have found an effective 'upstream' partner or range of partners among several advanced laboratories—or JIC could have found downstream partners among a variety of national research groups as well as, or instead of, the international centres. When collaboration is based on a single activity, as in the ICIPE–IACR–Rothamsted partnership, it is relatively easy to keep the partners tightly focused on the goals of the research. It is also easier to wind up the partnership if the project runs into trouble. In a multi-faceted partnership this is more difficult, especially where some sub-projects are succeeding and others are not, but 'good will' is important for the future of the whole relationship. This suggests the need for institutional arrangements which are more open-ended and less prescriptive, leaving scope for various strategic partnerships to be formed according to evolving needs.

Both relationships have at times faced problems of poor communication between the research partners and the question of who is the leader. The experience suggests that easy and frequent communication is essential (and that budgetary provision for this should be relatively generous) and that neither partner should regard itself as in the lead overall, though each should have clearly defined roles. Unless these conditions are met, some misunderstanding and tension are likely to emerge in the course of the work, whether or not it is organised in discrete sub-projects.

The need for flexibility in the choice of collaborating partners, and the potential value of these more informal collaborative relationships, is further illustrated by the story of CMD in Uganda.

In this case it was the *ad hoc* collaboration between NARO and SCRI, based largely on serendipitous contacts between individuals, which made it possible to characterise the Uganda variant of the virus. Modern communications make establishing such informal collaboration much easier than in the past, a fact which suggests that any national research team confronted with a new problem to solve should seek to establish the widest possible network of potential collaborators as a first step in tackling the problem.

Different questions about the nature of collaboration are raised by the partnerships between the international centres and the national research programmes. As explained in Chapter 2, the mandate of the international centres has shifted substantially, during the lifetime of the Gatsby programme, towards more active involvement in on-farm adaptive research, theoretically in collaboration with national programmes. However, this does not in itself solve the problem of making the partnership, which is supposed to extend to the applied and even the strategic parts of the research spectrum, more effective. Several of the Foundation's projects—including those on cassava, rice, *Mus*a and maize habitat management—depend for their success on the effective functioning of this partnership, but experience suggests that the relationship has often been troubled, particularly as the international centres seek to compensate for the weaknesses of the national programmes by increasing their own activities, a tendency seen in some quarters as an attempt to take over the role of the national programmes. However, a strong and effective relationship covering all parts of the spectrum is essential if the national programmes are to feel ownership of the technology they must subsequently adapt and extend more broadly.[1] For such a relationship to develop, it is vital that the international centres live up to their commitment to strengthen the national programmes through training and collaborative research, both in the laboratory and on the farm. It is a truism, but one that bears repeating in view of the current drastic under-funding of almost all public-sector agricultural research in the developing world, that such partnerships must be backed up by adequate resources to ensure that both parties can participate fully in the research activities.

Gatsby's projects to disseminate improved crop varieties have all included an element of farmer involvement in the evaluation of new materials and all the project partners have expressed their enthusiasm for participatory methods in general. On the whole, the researchers believe that the extra time and resources that they must invest in closer interaction with farmers pay handsome dividends in terms of the more rapid dissemination of more appropriate varieties, leading to higher rates of adoption. Although the rationale for farmer involvement in all cases is similar, the projects display considerable variability as regards the nature and level of farmer involvement and the degree of choice allowed them. Formal PVS methods were used in both the rice and beans projects, but the textbook approach adopted at first was subsequently relaxed to allow variations in the methods to suit local conditions.

The basic case for participatory selection is incontrovertible: varieties that have been fully evaluated with farmers and by farmers, under the management regimes prevalent on small-scale farms, and tested for consumer preferences, are much more likely to meet farmers' needs and hence to be widely adopted than are the products of a classical research station-centred selection process. Nevertheless, there are provisos: in PVS, as in conventional on-farm selection, each group of farmers only has the opportunity to evaluate the choice of varieties over one, two, or at most three seasons, during which the weather or pest pressure, or even other factors such as the state of the market, may be unusual, prejudicing farmers' choices. In the case of the Uganda cassava project, farmers accepted new CMD-resistant varieties under the extreme pressure of the mosaic disease epidemic but reverted to other preference criteria once the 'front' of the epidemic had passed. The initial uptake of these varieties concealed the fact that the plant breeders still have work to do in combining resistance characteristics with locally important cooking and processing traits. However, thanks to the close farmer-researcher interaction

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1 For a discussion of this issue, see: J. de Vriess and G. Toenniessen (2001). *Securing the Harvest: Biotechnology, Breeding and Seed Systems for African Crops*. CABInternational, Wallingford, UK, pp. 44 and 57.

involved in the campaign, the breeders now have a clear idea of what is needed.

A more interesting question is whether participatory selection actually leads to a wider choice of new varieties for farmers. This depends critically on varietal registration procedures and the operation of the seed distribution system (using 'seed' in the broad sense to encompass planting material of vegetatively propagated crops). There is little value in using a participatory approach if only one or two varieties are eventually registered and disseminated in quantity. Of the projects discussed, only WARDA's PVS strategy explicitly seeks to link varietal evaluation (by farmers and researchers) with the formal varietal registration process (by a government agency), with the intention of getting a wider range of varieties into the market place. In Uganda it can be argued that the success of NARO in gaining the trust of both government and farmers, its embrace of participatory methods and its involvement in both varietal evaluation and seed multiplication are all factors that bode well for the eventual registration of a wide range of cassava, banana and bean varieties. However, such a positive outcome cannot be taken for granted in all countries. Meanwhile, more participatory evaluation of varieties does at least mean more 'leakage' of improved varieties through the informal dissemination system prior to formal release, so there is some short-term increase in the amount of choice available to farmers.

Another question, even harder to answer, concerns the cost-effectiveness of participatory selection. The head of banana research in Uganda is quoted as saying that the number of trial sites previously used in on-farm research was too high for effective management (see Chapter 4, p. 33). Although farmer management of the trials can help to reduce the demands on researchers' time in the longer term, there are clearly short-term trade-offs to be considered: for example, between the number of sites and agro-ecologies to be included and the intensity of researcher–farmer interaction, and between the resources available and the quality of the eventual product. Evidently plant breeders and other researchers need to be fully familiar with the factors that determine farmers' needs—but they also need to have time to do the more strategic and applied research that underpins the innovation process.

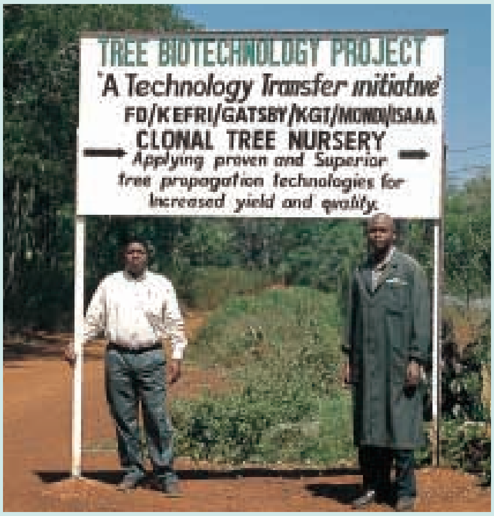
The choice of appropriate models of farmer–researcher interaction becomes even more critical when new crop management systems are developed. It is no accident that farmer participatory methods were first used on a large scale in IPM projects. Experience in many parts of the world has shown that farmers simply do not adopt pest- or disease-management 'packages' developed by researchers and disseminated as a unitary technology. The ICIPE-led maize habitat management project clearly illustrates how the scientists' original ideas (an insect-repellent grass between the rows, an insect-attractive grass around the plot) were unacceptable to farmers and had to be substantially modified. Push–pull was only adopted enthusiastically when a legume fodder crop was substituted as the intercrop. The ICIPE team also found that simply offering the technology package, even accompanied by on-farm demonstrations, was not enough. Farmers needed to understand the ecological principles of the new cropping system, especially the effects of the legume intercrop on *Striga*, before they were ready to adopt it.

Farmer participatory research of this intensity is relatively expensive to carry out and the costs of doing it properly must be taken into account especially carefully when attempts are made to disseminate knowledge-intensive technologies to larger numbers of farmers. This issue is discussed further below. For the time being, let us merely note that this problem will arise still more acutely in future if the evolving R&D agenda is to focus more attention on soil fertility and other 'system-level' concerns.

Once a new variety or crop management system has proved its value at a pilot level, who should take responsibility for its wider dissemination? Where does the responsibility of researchers end and what is the most effective role for external donors like Gatsby after this point has been reached? The approach to technology dissemination developed during the colonial period in Africa was based largely on an advisory service of extension agents; this was sustained and expanded during the post-independence years until (as noted in Chapter 1) financial pressures and policy shifts led to a dramatic reduction in the size and effectiveness of the service, especially over the past 10 years. Both local and international NGOs have stepped in to fill the vacuum to some extent, with varying degrees of expertise and effectiveness. But despite the expanded role of the NGOs, the negative consequences of the reduction of extension services have been dramatic, since the evidence suggests that such services, even in their reduced form, remain the prime source of information for farmers.

The Gatsby projects have to some extent found a productive way of working with a reduced extension service, particularly in the cases of the varietal dissemination work in Uganda and of the maize habitat management project in Kenya. In Uganda the selection by the NANEC system (see Chapter 2, p. 10) of a sub-county within an administrative district enabled the NARO cassava programme to have a decisive early impact in a limited area. This provided a basis from which to move out to other sub-counties within the district, a process co-ordinated by a senior extension officer for the designated crop at district level. The beans and banana programmes in Uganda adopted a similar approach, as did the *Musa* programme in Ghana. The maize habitat management project effectively adopts a comparable approach, although this is not formalised, in the six districts in which it now works in Kenya. In each of these cases, the researchers have control over the budget so that, through selective funding of extension efforts accompanied by intensive technical back-up, they can maximise impact in a limited area. Despite the success of 'researcher-managed extension' at this scale of implementation, there must come a point at which researchers should hand over to other players. These limits have yet to be fully explored and defined.

Different issues are raised by partnerships involving the private sector. The essence of the tree multiplication projects brokered by ISAAA and currently being implemented in Uganda and Kenya (see Chapter 5) is that the 'start-up' costs of infrastructural development and training have been met by Gatsby and, to a limited extent, by the Government of Kenya. In return, Mondi Forests has contributed intellectual property in the form of improved trees and the technology for multiplying them. In Kenya, both public-sector entities and a private-sector biotech company, GTL, are involved in the initial development and application of tissue culture techniques for multiplying the parent stock.



As governments in developing countries try to contain public expenditure, public-sector research and extension services are being severely reduced. To what extent can the private sector step in to fill the void? Innovative partnerships, such as that between Mondi Forests and the Kenya Forestry Department, brokered by ISAAA and primed with Gatsby funding (see Chapter 5), can bring together new technologies and the resources to promote their adoption, harnessing commercial processes to meet development needs and solve environmental problems.

Another company is being established to handle the larger-scale production of tree planting material and will pay royalties on audited sales of these to Mondi, which will thus be recompensed for the intellectual property it has contributed.

Evidently it would be a mistake to try to develop a single model for private–public partnerships in a field where diversity—of challenges and opportunities—is a byword. One lesson to be drawn from this experience, however, is that mechanisms can be devised to protect private-sector intellectual property so that it can be brought to bear on development problems in situations where the economic incentives, at least initially, are not sufficient to attract private financial investment and a purely commercial solution.

Scaling out

The international centres have always had the responsibility to support agricultural innovation across national and agro-ecosystem boundaries, while the national programmes of Africa are increasingly organising their own efforts within regional research networks. However, the existence of these links does not necessarily assure the effective transfer of new varieties and crop management systems from one place to another. For the purposes of this discussion, it is useful to distinguish between constraints which affect transfers across national borders (which may be statutory, such as quarantine regulations, or related to different social or economic policy environments) and those that come into play when crossing agro-ecological boundaries (which relate to the suitability of the variety or other technology to the biophysical environment).

Several of the Gatsby-funded projects have transferred technologies out of the system within which they were developed. In the case of the original Cameroon cassava project, varieties were readily transferred from Nigeria to neighbouring Cameroon, where farm ecology and consumer tastes were similar, but a new dissemination system had to be developed to fit in with the social and economic system; when similar varieties were transferred to Uganda, they coped with rather different agronomic conditions but did not appeal, once the CMD crisis was over, to local consumer tastes. In Uganda again, a variety of banana from FHIA in Central America was readily adopted, while bananas and plantains from IITA in West Africa found only niche markets or were not adopted at all. Now ICIPE's maize habitat management system is being transferred to very different contexts in Uganda, Malawi, Ethiopia and South Africa, while tree multiplication technology is being transferred from South Africa to Kenya and then on to Uganda.

Given the potential pitfalls, it is perhaps surprising that these transfers have worked as well as they have. However, in most cases, various kinds of local adaptation will be required if these technologies are to achieve their full potential in a new environment. In the case of disease-resistant cassava and bananas transferred to Uganda, a considerable further investment in breeding will be required *in situ* if long-term benefits are to be maximised. Further, NGOs, national programmes and indeed all partners in the technology transfer effort may emphasise germplasm distribution while underestimating the role of appropriate management practices in maximising the yield potential of the new varieties. Some level of participatory training, tied to the multiplication of planting material, can greatly enhance the chances of farmers' improving their crop management and so gaining maximum benefit from their new varieties.

Similar arguments apply to post-harvest processing and marketing opportunities. Different consumer tastes are often mentioned as an obstacle to inter-regional transfers of varieties, but in practice experience suggests that if the economic opportunities are sufficient, consumers and farmers can change their habits quite rapidly. In Ghana, yields of the new plantains from Nigeria are so much higher than those of existing varieties that they provide a powerful incentive for people to learn new ways of processing them. If a starch industry can be established in Uganda, quite a different set of cassava varieties will find a market. There is no way to 'prescribe' at a planning or organisational level the development of such opportunities, but Gatsby's experience has been that an energetic product champion will often, through informal networking, help to establish marketing opportunities or introduce processing ideas that can tip the balance in favour of adoption.

When new varieties are transferred from one country or region to another, the availability of good-quality seed (again defined to include vegetative planting material) represents both a potential constraint to adoption and, in theory at least, a new opportunity for enterprising farmers. In Uganda the popularity with consumers of some of the new bean varieties has led to enthusiastic adoption by farmers, to the extent that the availability of seed has become a serious constraint. Seed production can be a valuable source of income for farmers and Gatsby is helping to encourage this at community level by funding a Bean Seed Growers' Association. As in the case of schemes to multiply cassava (in Cameroon and Uganda) and *Musa* (in Ghana and Uganda), the public sector remains a necessary partner in these efforts, helping to provide quality control by, for example, maintaining varietal purity and ensuring disease-free foundation seed. However, such measures fall far short of what can be achieved in terms of quality, quantity and efficiency by larger-scale commercial seed producers within an appropriate regulatory environment. The inability of the small-scale and informal seed sector to respond to the demand for improved seed continues to limit the impact of more productive varieties in Africa—and is perhaps

Varieties and crop management packages that promise higher yields are not necessarily enough to ensure adoption and a positive impact on livelihoods. Farmers may need extra help (in the form of credit, crop insurance or subsidised inputs) if they are to adopt intensive production technologies like irrigated rice (left) that require them to invest heavily in labour and inputs and increase their financial risk. Disease-resistant and stress-tolerant varieties of cassava (Chapter 2) or upland rice (Chapter 3), which increase yields while requiring minimal inputs and reducing the risk of crop failure, may be much more readily adopted. In either case, marketable crops that provide opportunities for on- or off-farm employment in production and processing are likely to have the greatest positive impact on rural livelihoods.

one reason why even the most popular new varieties have shown little or no sign of displacing the diversity of local land-races.

As regards the transfer of crop management technologies, such as those developed under the maize habitat management project, the dangers of disappointment are even greater. The improved management system has been particularly successful for areas where there is a ready market for high-quality fodder and where *Striga* has been a significant problem. However, the time and other resources needed to adapt it to other circumstances are often under-estimated. This issue will become more important as Gatsby support increasingly embraces a cropping systems approach, as opposed to a single variety approach, to raising productivity.

An unavoidable conclusion from these experiences is that the outscaling of projects within African agriculture is very difficult. For a combination of the reasons mentioned here, and others related to them, the success of a project in one part of a country does not imply that it can be replicated and expanded country-wide or in neighbouring countries. Careful analysis of factors that are location-specific and others that are linked to particular socio-economic or agro-ecological systems can help those responsible for technology transfer to increase the likelihood of success. The exchange of positive and negative experiences can also be helpful. However, overall success in the current context is more likely to come, not through a grand strategy, but through a patchwork of individual projects, each of which will have its specific technical and institutional characteristics. The desire to explore a diverse range of possible models of innovation is one of the key reasons for Gatsby's support to the new Maendeleo Agricultural Technology Fund, which is being managed by FARM-Africa, an NGO, from its office in Nairobi. The Fund is inviting proposals from partnerships involving researchers, extension agents and farmers, leaving the applicants to define the nature of collaboration that may be most appropriate for particular situations.

Developing effective institutions

Discussion so far has emphasised the steps that Gatsby's project development partners and similar organisations have been able to take to increase the impact of technological innovation in agriculture. Notwithstanding the considerable success of such initiatives, there are some actions that need to be taken by national governments if major improvements in agricultural productivity are to be achieved.

Seed production is a case in point. The WARDA rice project, the NARO beans project and the ICIPE maize habitat project have identified a critical need for adequate quantities of seed and have taken steps to encourage community-based seed production. Such schemes have not been established long enough or extensively enough to demonstrate conclusively whether they will be successful, but experience elsewhere suggests that they are unlikely to be able to meet the challenge of scaling up to achieve large-scale impact. However, to date there are few examples of private seed production companies, outside South Africa, which are successfully meeting demand. It is for this reason that, in Guinea (Conakry), the successful upscaling of NERICA rice seed production was undertaken by government. In Nigeria too, the federal government has recently instructed a selection of state governments (through their ADPs) to take similar responsibility for seed production. Unfortunately, the history of such government enterprises has not been very encouraging, so the longer-term goal should be to establish in Africa the model of commercial seed production within a favourable economic climate and adequate public regulatory framework (providing seed certification, etc) which has served well in successful agricultural sectors elsewhere.

Similar issues arise in relation to fertiliser distribution, marketing and credit. In 2001, Uganda experienced a surplus of maize at a time when countries in Southern Africa were in deficit. However, the absence of any public body capable of setting a floor price, or of commercial enterprises capable of purchasing, storing or transporting the grain, ensured that maize remained uncollected in farmers' fields and that there was no incentive to sustain production at that level. Again, the history of commodity marketing boards in Africa has not been particularly successful and most have been scrapped in the course of structural adjustment and liberalisation; however, in most countries the private sector has not yet stepped in to fill the vacuum.

The lack of adequate credit, which may be needed for land preparation as well as for input purchase, has been highlighted by Mosley (in the Gatsby-funded policy study, see footnote 3 p. 7) and by many other observers as a major constraint on increasing the productivity of agriculture in Africa. As Mosley points out, the cost of seed, fertiliser, pesticide and weeding for just 1 hectare of improved maize is equal to about half the annual cash income of the average African smallholder. In Asian countries such as Bangladesh, where small-scale farmers have achieved a remarkable increase in productivity, independent or state-run rural banks have helped to provide micro-finance to farming households. When Zimbabwe achieved a mini-revolution in maize production in the 1980s, improved varieties, inputs and credit were all made available to farmers. Yet no country in Africa currently has a functioning nation-wide agricultural credit scheme. There is some scope for the new forms of micro-credit to fund agricultural production, as the experience of the Cameroun Gatsby Trust shows. [2] However, this will not be a universal panacea since there are serious problems in adapting group-based lending to the seasonality and unpredictability of crop production in the rainfed areas of Africa.

Finally, there is the vexed question of how best to reduce risk in agricultural innovation to an acceptable level. Unreliable rainfall, changing prices of products and inputs, and disruptions caused by civil strife are just a few of the risks that can turn a promising agricultural innovation into an unacceptable liability for small-scale farmers, who have few resources in reserve to act as a buffer against crop failure. Some of these risks can be mitigated or exacerbated by government action. As Mosley's policy study suggests, consistent government policies, perhaps combined with measures such as crop insurance, could encourage farmers to try out more innovations that would intensify production. In the meantime, as Gatsby's experience confirms, the innovations most likely to be widely adopted are those such as disease-resistant cassava, which offer increased incomes while stabilising, or even decreasing, risks.

The solutions to these problems will only arise from exploring a range of options and learning from experience. Thus the Maendeleo Agricultural Technology Fund will focus particularly on technology dissemination but will necessarily extend to issues of input supply and marketing. Finally, in this context, it is worth underlining once more that the organisational vacuum which exists in many of these areas means that the success of a technology-based development project is particularly dependent on the quality of individual leadership and the capacity of a 'project champion' to push the project towards success. Nearly all of the Gatsby-funded agricultural projects described in this report have been fortunate enough to have such a champion.

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[2] See: Building from the Base: The Work of the Gatsby Trusts in Africa. Gatsby, London, 1998 and www.gatsby.org.uk

The limits of technology

The overall picture generated by this record of Gatsby-funded projects is positive, confirming that, in the right circumstances, the products of agricultural research can be disseminated widely enough to benefit large numbers of small-scale farmers. The Foundation has shown that, by working both with 'traditional' partners, such as the international centres and the national programmes, and with newer players, such as the NGOs and private-sector companies, it is possible to help the small-scale farm sector to adopt relevant technologies.

However, Gatsby's experience also confirms that, under current conditions, there are limits to what can be achieved through technology dissemination, largely because key institutional and public policy questions affecting agricultural development remain to be resolved at the national and international levels. At present these policy questions, which revolve around such issues as credit, trade, access to markets and subsidies for inputs, are only partly resolved—or left open—through an unsatisfactory compromise between the pressures exerted by donor agencies, the action taken by national governments, and the measures imposed by international or developed-world institutions, many of which create conditions that penalise the small-farm sector in Africa and other developing regions. Much more far-sighted policy making will be necessary in both the developed and the developing world, but perhaps especially in the former, if the constraints that limit the impact of agricultural innovation on human well-being in Africa are to be lifted. Meanwhile, it is—we hope—useful to record experiences of successful, and unsuccessful, interventions in agricultural development, as a contribution to the knowledge base for planning more effective innovations in the future.

Gatsby is pleased to have been able to contribute to this end.

Acronyms

ADP	agricultural development project (Nigeria)
AFLP	amplified fragment length polymorphism
AHDT	Another Harvest Development Trust
BCMV	Bean common mosaic virus
BNARI	Biotechnology and Nuclear Agricultural Research Institute (Ghana)
BSV	*Banana streak badnavirus*
Bt	*Bacillus thuringiensis*
CABMV	Cowpea aphid-borne mosaic virus
CBB	cassava bacterial blight
CCEI	Caisse Communale d'Epargne et d'Investissement (Cameroon)
CGT	Cameroun Gatsby Trust
CIAT	Centro Internacional de Agricultura Tropical
CMD	cassava mosaic disease
CRI	Crops Research Institute (Ghana)
CSIR	Council for Scientific and Industrial Research (Ghana)
DaBV	*Dioscorea alata badnavirus*
DaV	*Dioscorea alata potyvirus*
DFID	Department for International Development (UK)
DNA	deoxyribonucleic acid
ECABREN	Eastern and Central Africa Bean Research Network
ELISA	enzyme-linked immuno-sorbent assay
ESARC	Eastern and Southern Africa Research Centre
FAO	Food and Agriculture Organization of the United Nations
FHIA	Fundacion Hondureña de Investigación Agricola (Honduras)
FHMC	Forest Health Management Centre (Kenya)
FORRI	Forestry Resources Research Institute (Uganda)
GTL	Genetic Technologies Ltd (Kenya)
HRI	Horticultural Research Institute (UK)
IACR	Institute of Arable Crops Research–Rothamsted (UK)
IC	immuno-capture
ICABR	International Consortium on Agricultural Biotechnology Research
ICIPE	International Centre of Insect Physiology and Ecology
IDRC	International Development Research Centre (Canada)
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
INIBAP	International Network for the Improvement of Banana and Plantain
IPGRI	International Plant Genetics Research Institute
IPM	integrated pest management
IRA	Institut de Recherches Agronomiques (Cameroon)
IRAD	Institut de Recherches Agricole pour le Developpement (Cameroon)
ISAAA	International Service for the Acquisition of Agri-biotech Applications
JIC	John Innes Centre (UK)
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
KULeuven	Katholeike Universiteit Leuven (Belgium)
NAARI	Namulonge Agricultural and Animal Production Research Institute (Uganda)
NANEC	National Network of Cassava Extension Workers (Uganda)
NARO	National Agricultural Research Organization (Uganda)
NCRI	National Cereals Research Institute (Nigeria)
NERICA	NEw RIce for AfriCA
NGO	non-government organisation
NRI	Natural Resources Institute–University of Greenwich (UK)
OFDA	Office of Foreign Disaster Assistance (USA)
PCR	polymerase chain reaction
PVS	participatory varietal selection
QTL	quantitative trait loci
R&D	research and development
RAPD	random amplified polymorphic DNA
RFLP	restriction fragment length polymorphism
RNA	ribonucleic acid
SCAR	sequence-characterised amplified region
SCRI	Scottish Crop Research Institute
SSR	short sequence repeat
USAID	United States Agency for International Development
WARDA	West Africa Rice Development Association
YMV	*Yam mosaic potyvirus*

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